Report of the Chicago Commission on Ventilation

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The Chicago Commission on Ventilation was organized in February, 1910.

Organization Members

Organizations having representation in the Chicago Commission on Ventilation, together with a list of members:

Chicago Department of Health

George B. Young, M. D. E. V. Hill, M. D.

Chicago Board of Education

John Wilkes Shepherd

Illinois Chapter of the American Society of Heating and Ventilating Engineers

Samuel R. Lewis James H. Davis

H. M. Hart

Illinois Chapter of the American Institute of Architects

George Beaumont

Illinois Society of Architects

Meyer J. Sturm

Western Society of Engineers

Fred J. Postel

Dedicated to one of
Humanity's Greatest
Assets—Public Health

Preface

The Chicago Commission on Ventilation is now in its fifth year, and this is its first publication. This publication appears for two reasons:

(1) In order that all members of the organizations holding membership in the Commission may have a detailed report of the Commission's work.

(2) In order to meet the requests from cities and from civic and other organizations that are asking for reports of the work of the Commission.

This report comprehends:

(1) A history of the organization of the Commission, including a statement of its methods and working principle.

(2) A statement of some of the problems undertaken by the Commission.

(3) Reports of tests made by the Commission on the ventilation of passenger cars, picture theaters, an experimental schoolroom, an office, and an experimental cabinet.

(4) The opinion of the Commission on phases of ventilation as set forth in resolutions.

(5) An appendix containing a description (in most cases an illustrated description) of the apparatus and methods used in the tests made by the Commission.

The organizations holding membership in the Commission are sufficiently established and also sufficiently varied in their purpose to bespeak the value of its findings. It is but fair also to state that almost all of the resolutions embodied in this report have been the subject of careful experimentation, from time to time, by members of the Commission.

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Organization of the Chicago Commission on Ventilation

The Chicago Commission on Ventilation was organized in February, 1910. The call for the meeting at which the organization was effected was made by Dr. W. A. Evans, who, at the time, was Commissioner of Health of the City of Chicago. In addition to Dr. Evans, the following named persons were present by invitation: Messrs. George Mehring, W. L. Bronaugh, and Samuel R. Lewis, members of the Illinois Chapter of the American Society of Heating and Ventilating Engineers; Dr. F. O. Tonney, Director of the Municipal Laboratories, City of Chicago, and Mr. J. W. Shepherd, from the Public Schools of the city. At this organization meeting, Mr. George Mehring was elected chairman, and Mr. J. W. Shepherd secretary.

A Commission on Ventilation Needed.

Full and free discussion on the general subject of ventilation was indulged in by all present at the organization meeting, and some of the conclusions reached may throw light on the purposes and methods of the Commission. All were agreed that:

(1) In the construction of new buildings, ventilation is not receiving the consideration which its importance warrants.

(2) Our present methods of ventilation are based on standards which are more or less traditional and without scientific foundation.

(3) All the factors which influence the ventilation of a building are not understood.

(4) The importance of ventilation makes it most desirable, if not entirely necessary, to conduct such experi-

ments as will make the practice of ventilation a branch of applied science.

First Representation on the Commission.

At the time of the organization, the Commission consisted of delegated representation from the Department of Health and from the Public Schools; also representative members of the Illinois Chapter of the American Society of Heating and Ventilating Engineers. Soon after the organization was effected, the three members who belonged to the Illinois Chapter of the American Society of Heating and Ventilating Engineers were authoritatively delegated as representatives from their society.

Formulation of Opinion.

From the beginning, it has been the custom of the Commission to indicate progress or clarify opinion through the medium of resolutions. These resolutions are formulated by the various members and reported to the Commission at one of its regular meetings. Resolutions must be reported at least one meeting prior to the time of their consideration and adoption or rejection. Moreover, when a resolution has been adopted, it may be reconsidered at any subsequent meeting.

The first resolutions were necessarily general in character, but aimed at fundamental principles, which must be considered in the practice of all ventilation.

Meetings.

It has been the custom of the Commission from the beginning to hold meetings on the first and third Tuesdays of each month, throughout the year, with the exception of the summer months. Call meetings, however, sometimes are issued even during the vacation period.

Added Membership.

Early in the year 1911, it became evident that in order to be most effective the Commission should have member-

ship from the Architects' organizations of the city. Accordingly, an invitation was extended to the Chicago Architects' Business Association and to the Illinois Chapter of the American Institute of Architects to appoint one delegate each to be a member of the Commission on Ventilation. Accordingly, Mr. W. H. Tomlinson was delegated from the Illinois Chapter of the American Institute of Architects, and Mr. Meyer J. Sturm from the Chicago Architects' Business Association.

At the close of the year 1912, Mr. W. L. Bronaugh and Mr. George Mehring found it necessary to withdraw from the Commission. Accordingly, Mr. H. M. Hart and Mr. James H. Davis then became members of the Commission from the Illinois Chapter of the American Society of Heating and Ventilating Engineers. At the same time, the pressure of outside work also compelled Mr. W. H. Tomlinson to withdraw and Mr. George Beaumont became the representative from the Illinois Chapter of the American Institute of Architects.

When Dr. George B. Young became Commissioner of Health in February, 1912, he accepted membership in the Commission. In January, 1912, the City of Chicago established a ventilation division of the Bureau of Sanitation, with Dr. E. V. Hill in charge. It was the sense of the Commission that the city's Chief Ventilating Inspector should be a member of the Commission on Ventilation, and Dr. Hill became a member in July, 1912.

The Western Society of Engineers accepted representation in the Commission and accordingly Mr. Fred J. Postel became a member of the Commission in January, 1914.

The Enlarged Membership of the Commission.

The Chicago Commission on Ventilation, as now constituted, is a delegated voluntary organization, composed of representation from the following organizations:

Department of Health of the City of Chicago.

The Illinois Chapter of the American Society of Heating and Ventilating Engineers.

The Public Schools of Chicago.

The Illinois Society of Architects.

The Illinois Chapter of the American Institute of Architects, and

The Western Society of Engineers.

The Commission's Working Principle.

The Chicago Commission on Ventilation believes that ventilation must become an applied science and, therefore, conclusions regarding ventilation must be open to revision in the light of experimental evidence.

The Work of the Commission

Except for the work done with the experimental cabinet, all studies and tests made by the Commission are made in rooms or buildings of full size, and substantially under normal conditions of use. Much criticism is sometimes offered against conclusions drawn from studies made with models or miniature structures usually housed within a room. If such criticism be just, then it is fortunate that our work was necessarily done in enclosures of full size and built in accordance with various architectural designs.

One of the first things the Commission undertook was to make a general study of the ventilation in restaurants, cafes, hotel dining rooms, bakeries, printing offices, office buildings, and other places in which health might be impaired because of the lack of good ventilation. Some of the present ordinances in the city code are based upon these studies.

From time to time, the work has become more definite and intensive. The following is a statement of the main line of work for the Commission during the year 1913-14:

(1) Tests were made with different classes of picture theater buildings. These tests were made with the buildings unoccupied. It was planned to make tests of an occupied theater, but these tests were necessarily postponed.

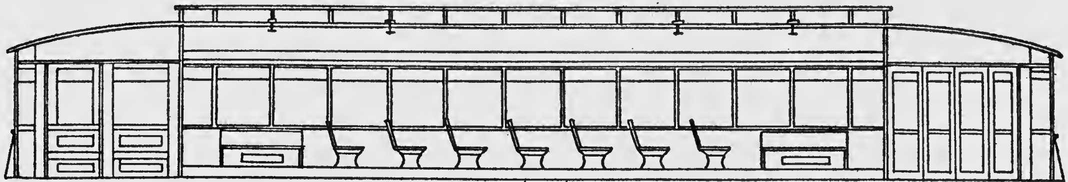
(2) Tests were made with street and elevated cars.

(3) Tests with the experimental cabinet were started.

(4) It was planned to make some tests of an unoccupied church building, but these could not be made in the time which the Commission had at its disposal. It is hoped, however, that within the coming year it will be possible to make these tests.

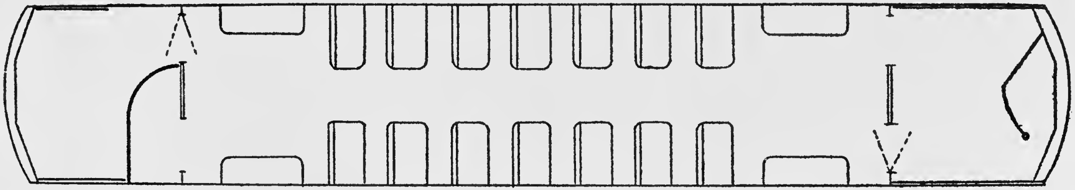
Most of the reports which follow are taken from the work done in 1913-14, and is fairly representative of what the Commission is undertaking. It is not to be understood that the work done on these lines is completed. The field is large and the conditions so variable that much remains for the future. The value of such investigations will increase in proportion to their number.

INSPECTION AND TEST SHEET No. 5



Elevation

DOUBLE END CAR-DECK SASH VENTILATION



Plan

COMPANY: ____________

				WEATHER CONDITIONS				TESTS IN CARS						DECK SASH VENTILATORS		
DATE	CAR NO.	RUN	TIME	WIND DIR.	WIND VEL.	TEMP.	R.H.%	TEMP.	CO_2	POINTS HEAT	DUST	NO. OF OCC'PTS	PRIMARY SENSE IMP.	OPEN RIGHT	OPEN LEFT	ANEMOMETER READINGS
2/4/13	214	Madison St.	5^{30}	W.	22	15°	78	46°	14.5 / 19.0	3	–	75	Fair	–	2 Rear	
2/5/13	185	Madison St.	7^{20}	W.	22	0°	74	45°	23.0 / 25.0	3	–	88	Fair	2 Front	2 Rear	
2/5/13	615	Madison St.	8^{10}	W.	22	1°	74	44°	21.0 / 25.0	3	–	70	Fair	2 Front	2 Rear	
2/5/13	240	Milwaukee Ave.	11^{15}	W.	22	5°	72	48°	15.0 / 15.5	3	–	51	Bad	2 Front	2 Rear	
2/5/13	2755	Halsted St.	11^{30}	W.	22	7°	72	46°	13.0 / 14.5	3	–	45	Fair	3 Front	—	
2/5/13	2765	Halsted St.	12^{15}	W.	22	8°	72	55°	8.5 / 11.0	3	–	58	Bad	2 Front	2 Rear	
TOTALS					132	36°	432	284°	205	18	–	387	—	TOTAL:		
AVERAGES:	$\frac{\text{TOTALS}}{\text{NO. OF TESTS}}$				22	6°	72	47.5°	17	3	–	64	—	INSPECTOR: Beckwith and Thompson		

M.J.M.

Street Car Ventilation. Test Record

Street Car Ventilation

The problems involved in street car ventilation must be considered under two distinct headings:

(1) Those relating to cars used for interurban transportation, such as day coaches and sleepers;

(2) Those relating to cars used for transportation within the city, as street and elevated cars.

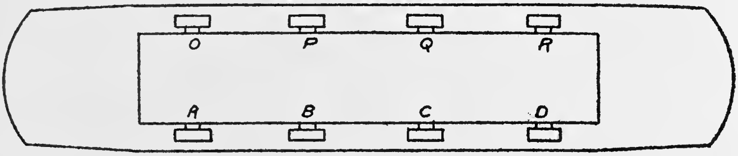
In the former class, the speed is relatively high, the stops infrequent, and the proportion of air space to passengers is large. With cars coming under this classification, the problem of ventilation is not so serious as with the latter class.

With regard to street and elevated cars operating within the city, these conditions are reversed. The speed is relatively low, the stops frequent, and the air space per passenger small; consequently the air leakage observed in cars traveling at a high rate of speed is almost entirely absent in this class. Moreover, the leakage is further reduced by modern methods of construction. The old loose window sashes that rattle with the movement of the car and the action of the wind have been replaced by metal sash and double glass construction, and arch-roofed cars are being substituted for the old monitor decks. The tendency is to make these cars virtually airtight boxes and the question of ventilation can no longer be left to chance.

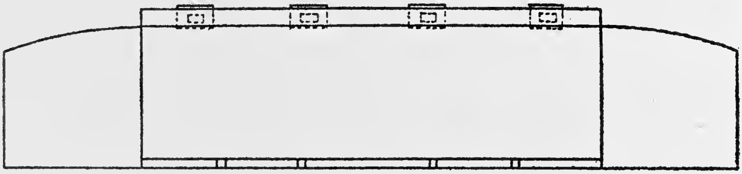
It is to be understood in discussing the ventilation of street and elevated cars we refer only to the operation of such cars during that part of the year when artificial heat is required. At such time, it is necessary that all windows be kept closed and that the doors remain open as short a time as possible.

The intramural transportation companies of Chicago are operating 4,600 cars. According to the Fourth Annual Report of the Board of Supervising Engineers, for the year ending January 31, 1911, the total number of passengers

Chicago Commission on Ventilation
Car Test Report



Plan



Section

CAR No.: 644 COMPANY: Chi. Rys. DATE: 4/2/13 TIME: 10:30 a.m. 2:30 p.m.

Type: Monita Deck

Inspector: Cahill

System of Ventilation: Floor Intakes; Exhaust at Deck Sash

Conductor: 4754

Motorman: 2485

	No.	Type	Location	Net Area □"	
Intakes:	8	7" Circular	Floor	38.484	Total Area: 2.138 sq. ft.
Outlets:	8	See Plan above	Deck Sash	6"x12"	4

Barometer Readings:

Right	A	B	C	D	E	F	G	Total cu. ft. hr.: 22,139
	50,040	26,550	53,100	47,500				
Left	O	P	Q	R	S	T	U	19,913
	58,690	34,940	46,580	30,900				

Time Length: 4 hour run from 10:30 AM to 2:30 PM.

Car Total cu. ft. hr.: 42,052

Outside Gen. Condition: Clear
Temperature: 16°
Wind, Dir. & Vel.: S.E. 17
R.H. %: 63
Dust: No Determination
Speed of Car: Av. 9 mi. hr.
Direction of Run: N.E. and S.W.
Inside Condition: Fair
No. of Occupants: 75
Sense Impression: Fair
Temperature: 52°
R.H. %:
CO_2, Parts per 10,000: 14-19
Dust: 19,600 m
Location of Reading: Front and Rear
No. of Heaters: 14
Type:
Points of Heat: 2

W.J.M.

Street Car Ventilation. Report Form.

carried for the period mentioned is 853,785,689, which is over 2,340,000 per day. At the present writing these figures can safely be increased 15 per cent.

Considering the restricted space passengers occupy in surface and elevated cars, especially at the rush hours, and the consequent intimate contact enforced, the necessity for proper ventilation of these cars becomes apparent.

Of the total number of cars in service—4,600—3,284 are operated by surface line companies, and 1,431 by the elevated companies. Of the surface cars, 1,982 are of the old monitor deck type, ventilated only by means of deck sash windows; 250 are equipped with so-called automatic ventilators, and 990 with mechanical exhaust appliances.

The Commission on Ventilation is making tests of the various cars in service to determine the relative efficiency of the different systems of heating and ventilating, and to decide, if possible, what would be reasonable requirements.

Tests.

In our investigations during the past two years, we have endeavored to determine four important elements:

(1) Air supply, at present obtained by the various methods of ventilation employed:

a—By anemometer readings,
b—By CO_2 analyses.

(2) Temperature maintained in cars in service during cold weather.

(3) Dust:

a—Amount,
b—Character.

(4) Bacteria.

Method of Making Tests.

In determining the air supply in mechanically ventilated cars, the following method is employed:

In one type of installation using a mechanical exhaust, each car is equipped with fourteen outlet registers situated in the ceiling of the car. The air is exhausted through these

registers into an air space between the head lining and the roof, by means of a 10⅝-inch cone fan driven by a specially designed direct connected motor. By means of a galvanized iron tube six inches in diameter, fitted with a coarse mesh wire screen at one end and a suitable fastening device at the other, an anemometer is suspended at each register. Test runs are made in every direction, covering a period of from two to eight hours, and the average velocity of the air through each register is determined. The velocity in feet per minute is multiplied by the area in square feet of the opening and by the number of openings, which gives the C. F. M. exhausted. The results obtained in this manner are checked by means of analyses to determine the amount of of carbon dioxide when the car is in service.

For taking air samples, an ordinary Paquelin cautery bulb with about sixteen inches of rubber tube is employed. Four samples are usually taken at a time in an occupied car, in the same manner as in theaters and other ventilation work. (See appendix.)

Analyses for carbon dioxide are made to determine the amount and distribution of the fresh air supply and not because it in itself is considered injurious in the amounts found, or that it is an indication of other organic impurities.

In cars equipped with automatic ventilators, an anemometer is placed in each outlet opening. In the cases of ceiling outlets, the method used is the same as just described. Where the ventilators have been installed in deck sash openings, the anemometer is fastened to the lower rail of the deck sash. Tests are then made in a car running in every direction and CO_2 analyses made as a check on the anemometer readings. In cars ventilated only by deck sash windows, the carbon dioxide anlyses are relied upon to determine the air supply. In all of these tests, careful observations of the outside weather conditions are made, the temperature of the air, direction and velocity of the wind having a very important bearing on the efficiency of the ventilating equipment. This is especially true of the automatic ventilators, as the amount of air exhausted depends

almost entirely on the speed of the car and the direction and velocity of the wind.

Temperature.

Temperature observations are made in four locations within the car, at the waistline of seated passengers.

Dust.

Dust determinations are made by the filter method. For this work, it is necessary to run a special car without passengers, as the noise of the machine and the observations necessary would seriously interfere with the comfort of the passengers. These tests are made for the purpose of determining the effects of various intake locations on the dust content, and the fact that the car is unoccupied is of no importance.

Bacteria.

Quantitative determinations of the number of bacteria are made by substituting sand for sugar in the filter and plating, incubating and counting the same according to the method described in the appendix. Rough approximations of the quantitative tests are made by exposing standard Petrie dishes for two minutes in occupied cars. The method of recording and reporting these various tests and observations is given in the accompanying charts and diagrams.

(See Charts, pages 12 and 14.)

Discussion.

These observations have not been carried on for a sufficient length of time to warrant the commission in publishing conclusions. We feel, however, that the work so far merits the reporting of certain pertinent observations. It is apparent from the work done that the method of ventilating street and elevated cars by means of deck sashes is very unsatisfactory. In cold weather, disagreeable drafts are produced when the deck sash windows are open. During rain or snow

storms they must of necessity be closed. With a crowded car when this method of ventilation is used, repeated tests have demonstrated that the air supply per person will fall as low as 4 or 5 cubic feet per minute. This condition has been apparent for some time to the public and to persons investigating the question, and at the present time, the transportation companies have given tacit acknowledgment to the fact, and are not purchasing or building cars of this type. The next step forward was the substitution of the so-called automatic ventilators. These operate on the principle of the "T" tube, and depend for their efficiency on the speed of the car and the direction and velocity of the wind. They have some features to recommend them; they are not expensive to install or maintain, and are always in operation. The serious objection, however, to their use is that the air supply cannot be controlled, since it depends entirely on the velocity at which the outside air passes through the device. When cars are in service in congested districts, they are moving slowly and make frequent stops. They are also loaded to their maximum capacity. This is the time when the greatest air supply is required. Owing, however, to the slow speed and frequent stops, the automatic ventilators are operating at their lowest efficiency. As the car leaves the congested district of the city, the number of passengers decreases, the stops become less frequent, and the speed becomes higher. The automatic ventilators, at this time, are working at their maximum efficiency, but at a time when the least amount of air is required.

The mechanical method of ventilation, by means of plenum or exhaust fans, is a comparatively new proposition and is being taken up by the transportation companies with reluctance. Such systems are more expensive than the automatic ventilators, require more attention, and there is a slight expense for operation and maintenance. It is, however, perfectly apparent that up to this time an adequate air supply properly distributed and under control can be obtained in no other way. With mechanical ventilation the amount of air required is actually supplied. No street car yet placed in service in the city of Chicago has heating surface of capacity sufficient to warm this amount of air.

This causes the real objection on the part of the transportation companies, to mechanically ventilated cars.

While the mechanical systems at present in use are open to criticism in some details, we feel that unless great improvement is made in natural systems, for many excellent reasons, mechanically ventilated cars should be required in all cities.

Picture Theater Ventilation

From the standpoint of methods for ventilation, the picture theaters in Chicago fall into five classes or types, as follows:

(1) Unventilated.

(2) Ventilated by exhaust fans only, without definite provision for air supply.

(3) Theaters ventilated by exhaust fans at one end, with suction air supply through tempering coils at other end.

(4) Theaters ventilated by supply fans forcing air through tempering coils at one end and exhausting by pressure at the other end.

(5) Theaters ventilated by supply fans forcing air through tempering coils and special distributing ducts and inlets, exhausting through distributed outlets with or without fans, temperature control, etc.

During the winter of 1913-14, the Commission has made tests of several picture theaters in the city. These tests were made with the theaters unoccupied. The aim was to determine the general movement of air within the theaters, and this could be done quite as well without the usual picture theater audience. In order to produce convection currents somewhat similar to those set up by the audience, standard candles were placed on the seats and lighted.

Some tests were made with a candle in each seat and others with candles in alternate seats. The purpose in using the candles in the latter arrangement was to produce approximately the same amount of heat and CO_2 that would be produced by an audience.

The candles did more than merely to furnish convection currents within the audience chamber as may be noted in the following reports on the ventilation of typical theaters under classes 2, 3, and 5. If the convection currents were not interfered with by longitudinal currents, one would ex-

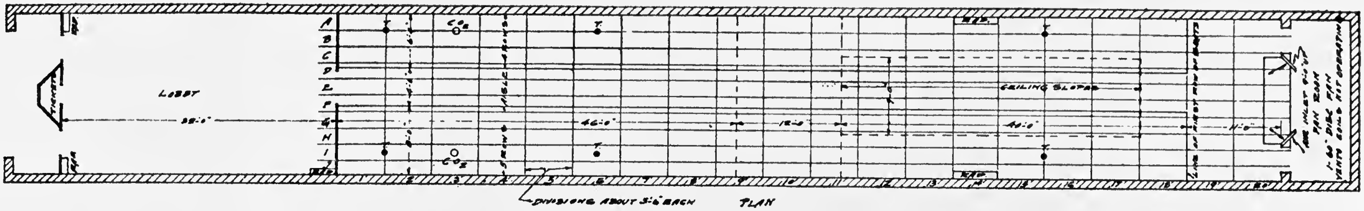
pect the maximum content of carbon dioxide to be found in the upper stratum or air. The facts, however, were that in general the maximum carbon dioxide content did not occur in the upper stratum, for the reason that longitudinal air currents were found especially along the ceilings, due to the general method of air introduction and removal.

The general longitudinal air movements were studied by means of clouds of ammonium chloride formed from the intermingling of gases or vapors from concentrated ammonium hydroxide and concentrated hydrochloric acid.

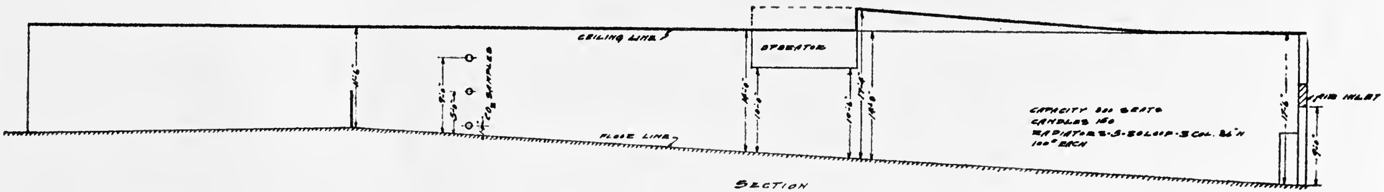
The behavior of the general longitudinal and vertical currents combined was studied by means of toy balloons which were inflated with hydrogen gas and counterpoised by means of weights, in order that the balloons might follow the currents in which they were placed. In some instances it was difficult to obtain satisfactory results, because of the very great difference in temperature between the incoming air and that which had been in the room for a few minutes. This condition was particularly true in theaters in which the supply of air for ventilating purposes was brought in through the doors.

It is only in the construction of recent picture theater buildings that a general attempt has been made to provide both inlets and outlets for ventilation purposes. Except in special cases, in the older types no effort was made to provide either inlets or outlets.

So far as the comfort as well as the health of the theater patrons is concerned, there needs to be required a better connection between the heating and the ventilating of picture theater buildings. Specifically, it is evident from our investigations that the air for ventilation purposes should be compelled to pass through heaters before it comes in contact with the audience.



Senate Theater, Plan.



Senate Theater, Section.

Test of Senate Picture Theater,

736 W. Madison Street, Chicago,

February 21, 1914.

See Plans, page 22.

Type.

The theater is classified under Type 3 in the introduction. The fan draws air through vento heaters and forces it into the room. The air finds its way out through doors and windows, no special outlet being provided.

Seating Capacity.

Seats are provided for three hundred.

System of Heating.

Low pressure gravity steam. Theater is supplied with five (5) 100 square foot direct radiators, with 300 square feet of vento for tempering the air.

System of Ventilation.

Supplied by dilution under fan pressure, the fresh air diluting and displacing vitiated air, the latter escaping from the auditorium through the lobby and entrance doors. It is possible to keep these doors open on account of the extreme length of the lobby.

Intake.

Thirty-six-inch, circular, through roof fourteen feet above alley grade.

Supply Fan.

One full housed steel plate blower with a wheel forty-two inches in diameter, speed 350 R. P. M., delivering 6,000 cubic feet of air per minute.

Inlet Openings.

Two grilles about nine feet above the floor at front end of theater.

Exhaust Fans.

None provided.

Outlet Openings.

No special provision is made for outlets on account of the peculiar construction of the building, the entrance doors being continuously open and serving this purpose.

Discharge Openings.

None provided.

Heater.

Consists of three stacks of regular forty-inch vento, nine sections to each stack. At the time of the test the coils were not operating properly, owing to some trouble with the air valves or other connections.

Test—With Fan Running.

(a) Time—9:45 to 11:30 a. m.

(b) Temperature—Outside was plus 28 deg. F. throughout test. One hundred and fifty standard candles, corresponding closely in heat output to 300 occupants, were evenly distributed on the seats throughout the auditorium, one candle being placed on each alternate seat. These

heated the theater from plus 60 deg. F. to plus 80 deg. F. in a very short time. The temperature was very rapidly lowered as soon as the fan was turned on. (See chart on plate 3.)

(c) CO_2 Test—Samples were taken as marked on the plans at levels of 1, 5, and 9 feet above the floor in each location. The sample bulb was broken after two sets of samples had been collected; analyses of these samples, however, gave an average of 7.1, 8.8, and 8.2 parts of CO_2 at the levels previously mentioned.

Thermometer Readings.					
	Fan not Running		Fan Running		
No.	9.45	10.00	10.25	10.40	Outside
A-1	71½	80	69½	67	28°
I-2	73	82½	69	67	28°
A-6	69½	78½	62½	62	28°
I-6	69½	77½	62	62	28°
A-16	69½	76	56	59½	28°
I-16	69½	78	51½	60	28°

(d) Ammonium Chloride Test—The ammonium chloride was liberated at the inlet openings. It traveled the length of the room in one and a half minutes. With the doors open and the fan running the air became clear in ten minutes.

(e) Bacteria, Relative Humidity, and Dust—No tests to determine the number of bacteria, the relative humidity, or the number of dust particles were made.

(f) Balloon Test—Standard balloons were liberated at the inlet openings. The course taken by these balloons indicated that a part of the fresh air currents struck the projecting operator's room, turned upward and returned along the ceiling towards the point of air introduction. Other balloons passed underneath this projection and traveled to the rear of the theater, indicating that probably three-quarters of the air supply followed this course, traveling the length of the auditorium, thence into the lobby and out the exit doors. When the entrance doors were closed some of the balloons passed backward from the inlet openings to the projecting operator's booth and from this point

descended directly to the floor line, where they remained with very little movement. When the doors were opened, however, these balloons passed backward to the rear of the theater with a slow and uniform velocity.

Discussion.

The rapid rise of temperature, due to occupants (candles) is striking. It is also evident, from the quick drop in temperature when the fan was started, that untempered air cannot be introduced into a theater in cold weather, for despite the fact that the direct radiators were all hot, the temperature fell from 80 deg. when the fan was started to from 51 deg. to 69 deg., depending upon where the observations were made, in twenty-five minutes. This was undoubtedly due to the fact that the tempering coils were air bound and inoperative. The operator's room is located in a peculiar manner, being about midway between the front and rear of the theater and projecting downward within ten feet of the floor. (See plan.) The situation of the operator's room, as described, has the effect of breaking up the air currents from the inlets and makes it rather difficult to obtain proper air distribution. The analyses of the air samples and the behavior of the balloons, together with the ammonium chloride test, indicate that the air currents at the front of the theater are broken up at the operator's booth. Back of this point the air currents are hardly noticeable, but the air supply and distribution are good.

Deductions.

The drop in temperature when the fan was in operation emphasizes the fact that proper installation and operation of tempering coils is imperative. It is also necessary that provisions be made properly to control the temperature of the incoming air. There must be provided adequate means of air discharge, usually independent of the doors or windows. In this instance, however, the peculiar construction of the building, viz.: the long lobby, makes it possible to utilize the entrance doors to advantage.

Test of Austin Picture Theater,

5619 W. Madison Street, Chicago, Ill.

BY THE CHICAGO COMMISSION ON VENTILATION,

March 7, 1914.

See Plans, pages 28 and 29.

Type.

This theater is classified under Type 5 in the introduction. The fan forces air through a heater and the ducts, and into the room by distributed floor inlets. The air is driven out through openings in the ceiling by the fan pressure.

Seating Capacity.

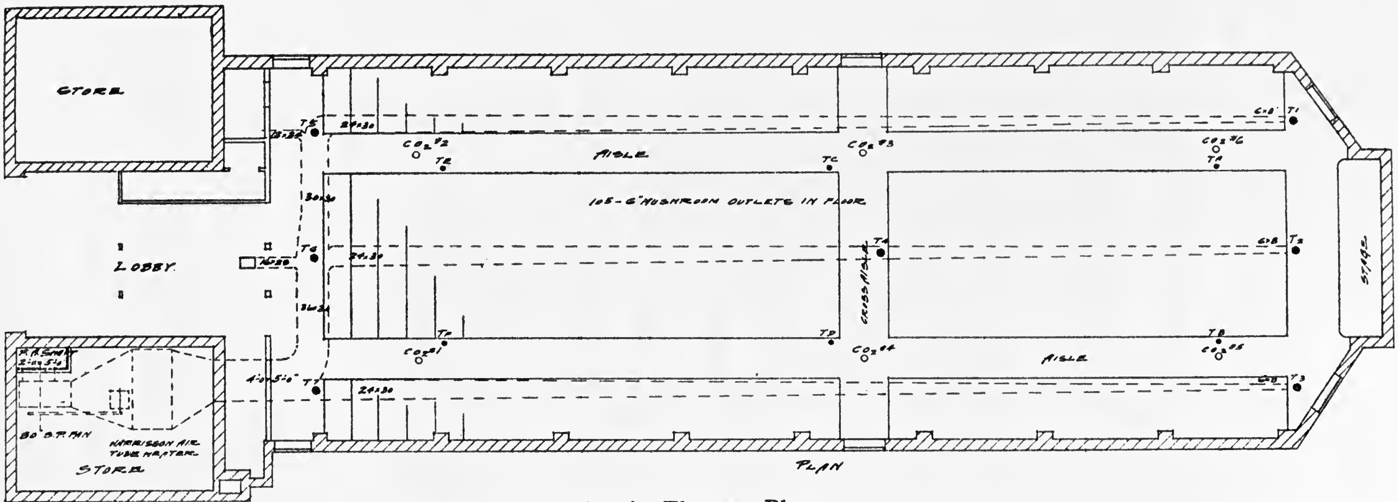
Five hundred and thirty-three.

System of Heating.

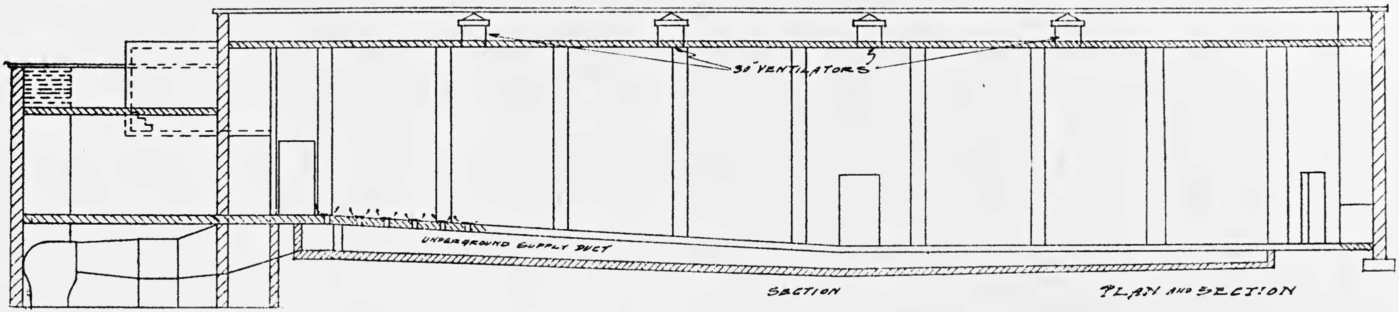
Furnace plenum system. The furnace is under the highest part of the sloping floor. The heated air must be driven down the inclined masonry ducts, against its natural tendency to rise, a distance of about 75 feet to drainage point, thence through balance of duct 50 feet with a slight upward incline. The ducts contained from one-half to two inches of ice and water at drainage points. This had accumulated, as the building had not been in use or heated for several months previous to test. There are no direct radiators. The building can be heated only when the fan is in operation. There is danger of overheating and resultant injury to the furnace if the fan is not operated when the furnace is fired.

System of Ventilation.

By displacement under fan pressure. The incoming air is introduced into the theater through 105 six-inch mush-



Austin Theater, Plan.



Austin Theater, Section.

room inlet openings distributed under the seats of the theater and the air escapes through outlets in the ceiling.

Intake.

From a point three feet above the roof line 2x5 feet in size.

Supply Fan.

One full housed steel plate blower with wheel 48 inches in diameter, 378 R. P. M., delivering 15,000 C. F. M.

Inlet Openings.

One hundred and five in number, six inches in diameter, capped with adjustable mushroom deflectors.

Outlet Openings.

Four, 30-inch in diameter, located in the ceiling.

Exhaust Fan.

None provided.

Discharge Openings.

Same as outlet openings.

Heater.

One No. 80 Harrison air tube furnace. This is a coal burning firebox below a series of horizontal iron tubes, through which the air is forced by the fan. The heater contains 64 four-inch tubes.

Test—With Fan Running.

(a) Time—11:30 a. m. to 1:30 p. m.

(b) Temperature—The outside temperature was plus 33 deg. F. throughout the test. Two hundred and sixty standard candles, corresponding nearly in heat output to 533 occupants, were distributed on alternate seats. Temperatures noted at various times and at different points are indicated on the plans. Thermometer stations shown by "T" were five feet above the floor. Thermometer stations in the supply ducts are shown by 1-2-3, etc. The temperature of heated air at the furnace was in excess of plus 210 deg. F., the limit of the thermometer. It was probably as high as 400 deg. F. The tubes of the furnace became red hot, as did the breeching.

(c) CO_2 Tests—Samples were taken at "A," "B," "C," etc., marked on the plans, at levels 1, 5, and 9 feet above the floor. These samples were unsatisfactory, due to some mistake in technique.

Station		11.53 A.M.	12.25 P.M.	12.55 P.M.	1.15 P.M.	1.30 P.M.	1.45 P.M.	Air Vel.
Duct Stations	1	40	54	60	63	65	72	580
	2	39	54	65	69	70	72	464
	3	38	55	61	67	67	64	430
	4	39	84	100	103	111	111	650
	5	39	111	128	135	141	144	770
	6	39	110	130	138	140	142	820
	7	39	108	124	130	138	142	830
House Stations	A	36	46	52	58	61	63	
	B	37	50	56	63	66	67	
	C	37	54	58	64	67	68½	
	D	37	54	58	65½	68	70	
	E	39	56	64	71	74	76	
	F	38	56	64	74	74	77	

(d) No ammonium chloride test was made.

(e) Bacteria, Relative Humidity, and Dust—Tests to determine the number of bacteria, the number of dust particles, and the relative humidity were not made.

(f) Balloon Test—The standard balloons were liberated at various points in the theater; first, at about four feet above the floor, along the front row of seats nearest the stage. These balloons took a uniform course backward over the tops of the seats, moving at a very slow velocity. They would usually gain a position in the aisle and pass backward to the low point of the auditorium at about 40

feet from the stage. Here they would rise vertically to within three or four feet of the ceiling, pass forward to the stage and down again to the point where liberated. One balloon, it was noted, made this excursion six times. At the end of the sixth circuit, it escaped into the large ceiling vent. Some of the balloons, if they succeeded in passing this central point in the theater, traveled backward toward the rear at a uniform low velocity, showing a continuous preference for the aisles.

(g) Anemometer Test—Anemometer readings are marked on the plans. The mushroom deflectors were removed for temperature and anemometer readings No. 1 to No. 7.

Discussion.

The theater is architecturally handsome, but the construction and arrangement of its heating plant is unfortunate. The roof slab forms the ceiling without any insulating space. The distributing ducts are wet, rough, and incline downward from the furnace to the central point, and then slightly upward to the stage end of the theater. Apparently no attempt had been made previous to test to equalize the air distribution by means of proper adjustment of mushrooms. After three hours of continuous operation, in order to maintain a temperature of plus 64 deg. at the end of the theater nearest the stage, which is farthest situated from the heating plant, the end nearest the heater was warmed to plus 80 deg. F. The owner evidently intended to secure a high-grade ventilating system, which embodied provision for reasonable air distribution and a uniform temperature. The cold ceiling, the wet ducts, and the improper location of the heater all combine to defeat this end.

Deductions.

An underground masonry duct must at all times be dry. The ducts must be well proportioned. In systems of this type, they should not run downward from the heater, owing to the inherent difficulties in heat distribution. They must be carefully tested and the delivered air must be thoroughly

equalized. When starting the heating plant in a cold theater, equipped with masonry ducts, sufficient time must be given to warm the ducts thoroughly. It is improper for ventilating purposes to heat even a small quantity of air to a high temperature. The air supply should be large in volume and comparatively low in temperature if good results are to be obtained. The ducts must never be heated to such extent that the introduction of air at a temperature lower than the air in the room is prevented. The incoming air must be cooler than the air in the room to prevent an excess temperature when a large percentage of seats is occupied. Some local means of heating at the end farthest from the heating plant seems desirable. Such wide variation of temperatures as were found here is most objectionable. There should be simple and efficient mixing dampers at the furnace so that part or all of the air may be by-passed around the heater as requirements indicate. Perfect drainage of ducts is of vital importance.

Test of Bell Picture Theater,

2407 W. Madison Street, Chicago, Ill.

January 10, 1914.

See Plans, page 35.

Type.

This theater is classified under Type 2 in the introduction. Exhaust fans draw the air out. It is supposed to enter through doors and windows and two openings provided at the floor line in the opposite end of the theater.

Seating Capacity.

Three hundred and fifty.

System of Heating.

Low pressure gravity steam with direct radiators.

System of Ventilation.

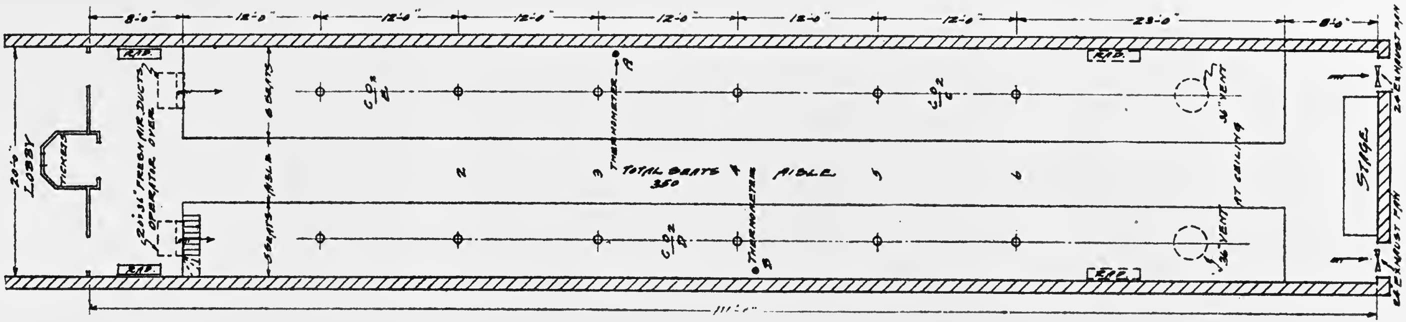
Exhaust, by dilution. No special provision has been made for heating the entering air.

Intake.

No special provisions made for intake. Air must gain entrance through lobby doors. Two 20x36-inch openings in the floor at the rear of theater, allowing some air to enter from the lobby.

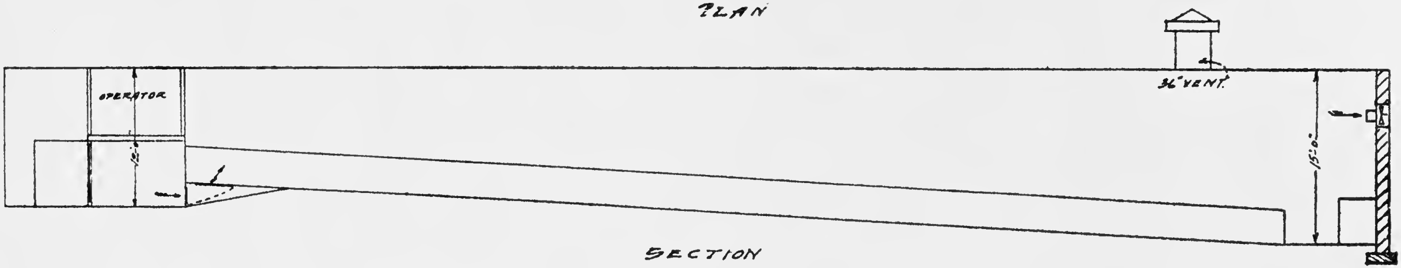
Outlet Openings.

Directly to fan placed in the rear wall.



Bell Theater, Plan.

PLAN



SECTION

Bell Theater, Section.

Exhaust Fans.

Two 24-inch propeller type fans situated in the front wall of the theater, one on either side of the stage; capacity, about 4,000 C. F. M. each.

Discharge Openings.

Two 36-inch roof ventilators are provided. These were closed at the time of test. The fans discharge directly to the outer air.

Heater.

Test—With Fans Running.

(a) Time—11:30 a. m. to 1:00 p. m.

(b) Temperature—The outside temperature was plus 27 deg. F. One hundred and seventy-five standard candles, corresponding nearly in heat output to 350 occupants, were distributed throughout the theater, one being placed in each alternate seat. The various temperatures noted are marked on the plans. The direct radiators were hot.

(c) CO_2 Test—Samples of air were taken at points one-third, one-half, and two-thirds of the distance from the entrance to the stage of the theater, at levels of 1, 5, and 9 feet from the floor. The averages at the one-foot level were 7.2; at the five-foot level 7.3; and at the nine-foot level 6.9 parts of CO_2 per 10,000 parts of air.

(d) Ammonium Chloride Test—This was made with the doors open and both fans operating. It required ten minutes to clear the air in the room.

(e) Ammonia Test—Standard Shepherd phenolphthalein cartridges were placed as marked on the plans about five feet from the floor. Ammonia was introduced at the entrance. The cartridges showed no reaction.

(f) Bacteria, Relative Humidity, and Dust—No tests to determine the number of bacteria or of dust particles, and no relative humidity observations were made.

(g) Balloon Test—Standard balloons were released: No. 1 from an open door. This passed along the floor, down the aisle, and stopped after traveling half way to the stage. No. 2 traveled the entire length of the theater at the floor line in the aisle in thirty seconds. No. 3 followed the course of No. 1 to the center, then rose to the ceiling and moved slowly towards fan "L," stopping permanently about thirty-five feet from the fan at the ceiling. No. 4 and several others were released near the entrance doors when the latter were closed. The balloons moved very slowly, sometimes in the aisles and sometimes under the seats, to about the center of the theater; they remained at the floor line. No. 5 and several others were released in the center of the length of the theater at the sides, with the doors open. They moved toward the exit end about twenty feet and stopped at the floor.

Discussion.

In order to ventilate this theater to any appreciable extent, it was necessary for the entrance doors to be open. The theater could not be heated with the doors open. The air movement was sluggish when the doors were closed. With the candles and radiators in operation, the temperature rose to only plus 61 deg. F., when the outside temperature was plus 27 deg. F. Evidently the room cannot be heated adequately in zero weather with the fans operating. The incoming fresh air if cold tends to create drafts along the floor, as indicated by the balloon tests. This incoming air, if at a low temperature, travels at the floor line until it has passed about half the length of the theater, when it becomes broken up and mixed with warm inside air. From here it rises and takes a more or less direct course toward the exhaust fans.

Another interesting observation was that the air currents, as indicated by the balloons, tended to follow closely and be confined to the limits of the aisles.

The analyses of the air samples indicate that about 1,500 cubic feet of air were being supplied per person per hour in the breathing zone.

Deductions.

It is necessary that adequate air inlets properly located be provided. Provision must also be made for properly regulating the temperature of the incoming air. No ventilation of any value is in effect when the doors are closed, and cold drafts, as well as operative conditions, militate against the doors being left open continuously in cold weather.

In systems of this type, it is very important that the temperature of the incoming air be controlled, as the cold air will follow the floor and create objectionable drafts. If the air is too warm, it will rise to the ceiling and pass over the breathing zone.

An Experiment in Ventilating a School Room

One of the first experiments determined upon by the Chicago Commission on Ventilation pertained to the ventilation of a schoolroom. For a long time many of the teachers of the public schools of Chicago complained of the ventilation within their rooms. Therefore, with the hearty approval and co-operation of the Board of Education, the experimental work was undertaken in the autumn of 1910. The attitude of the Board of Education has always been to improve the present system of mechanical ventilation within our public schools, if possible. All expenses in connection with the experiments on schoolroom ventilation are gladly borne by the Board of Education.

The public school buildings of Chicago are equipped with the plenum system, operating at a pressure of approximately one-half ounce.

Place of Experiment.

The Chicago Normal College, Sixty-eighth street and Stewart avenue, Chicago.

Time of Experiment.

The experimental work has continued from the autumn of 1910.

Quantity of Air.

The first tests made were somewhat in the nature of checking up the work of the builders. A rule of the Board of Education requires the delivering of a minimum of 1,800 cubic feet of air per pupil per hour. Anemometer readings made in several of the rooms of the Normal College showed that this amount was being delivered. There remained,

however, a closely related question: namely, whether or not each pupil is supplied with his share.

Distribution of Air.

Studies were made for air currents in two classrooms and one laboratory room.

Devices Used.

The tests for air currents were made by the use of toy balloons which were inflated with hydrogen gas and counterpoised in the rooms by means of improvised weights. In addition to the toy balloons, small turbine wheels were used. These were made from aluminum, cork, and steel needles, and were especially constructed for these tests. The blades of the turbines were made from aluminum and set into hubs of cork. Across one end of a cork hub and parallel with the plane of the blades, was fastened a strip of aluminum containing a slight indentation in which the pivot of the device turned. The fine point of a steel needle served as a pivot, and when ready for use the turbine revolved in a horizontal plane. These turbines are very sensitive to vertical currents of air—in fact, they respond to convection currents from the heat of one's hand. The counterpoised balloons were useful in tracing all air currents, irrespective of their direction, whereas the turbine wheels could be used only in testing for vertical currents.

Tests for Air Currents.

One of the classrooms tested is 25 by 25 feet and has an east exposure. The other walls of the room have no immediate contact with the outdoors. The inlet and outlet ducts in this room are installed in the north wall, and the air enters the room with a velocity of about 650 feet per minute. When balloons were pushed into the entering currents, they were hurried across the room near the ceiling to the south wall. From the ceiling at the south wall, the balloons usually took one of two general courses, depending largely upon

outdoor weather conditions. If the outdoor temperature was low and the wind was blowing directly against the windows, then the balloons moved over to the outside wall, down the wall or windows, and over to the outlet duct. If the outside temperature was moderate, then instead of the balloons crossing over to the outside wall, they were likely to poise in the southeast corner of the room, or possibly move vertically down along the wall opposite the inlet duct to within a foot or two of the floor, and then over to the outlet duct. It was very noticeable that air currents established themselves in aisles and other open spaces along the floor. During the winter season the turbine wheels, when placed on the window ledges, revolved almost all the time. Their direction of rotation indicated the downward movement of a sheet of cold air; moreover, this sheet of cold air was very perceptible to any one seated near the outside wall or windows.

The other classroom is 26 by 45 feet; is a northwest corner room. It has about twice as much exposure on the north as on the west side. As already stated, there are two inlets and two outlets in this room, and they are located in the long inside wall. The velocity of the incoming current of air was practically the same as in the smaller room. Anemometer readings showed an adequate supply of air for good ventilation. Balloons placed in the incoming current were hurried across the room to the opposite wall, the outside wall with the north exposure. After reaching the outside wall, they almost always went vertically downward to within a foot or two of the floor; then they moved over to the outlets near the floor and almost directly under the inlets. The hot incoming air driven against the cold outside north wall and windows, reduced the influence of wall and window chill. But in cold weather, especially with a north or northwest wind, a downward moving sheet of cold air was very noticeable. The small turbine wheels revolved constantly in cold weather when placed upon the window ledges or near the exposed walls. In the central part of the room, that is, between the two sets of inlet and outlet ducts, the balloons did not show perceptible air currents. Fur-

thermore, there seemed to be eddies in close proximity to the currents at either end of the room.

The laboratory room in which the tests for air currents was made is 26 by 45 feet, and is a northeast corner room. It has about twice as much exposure on the north as on the east side. The room has two inlets and two outlets on the long inside wall. The inlet duct at the west end of the room is so close to the west wall and ceiling that when the current of air is delivered against the north or outside wall, it takes a diagonal course downward and inward along the north wall, and across the windows. By this action of the air current shown by balloon tests, there is a considerable section of the west end of the room in which no perceptible air currents can be found. At the east end of the room, the air current behaves as might be expected, namely, the incoming air crosses from the south to the north end of the room along the ceiling, strikes the cold outside wall and windows, drops vertically downward, and moves over to the outlet. Turbine wheels placed near the windows or outside wall during cold weather were constantly rotating. The direction of rotation indicated a downward current of air.

Conclusion.

From the evidence obtained in the use of the balloons and turbine wheels, it is fair to conclude that air within the schoolrooms tested did not act as anticipated in the plenum system. Moreover, the action of the balloons and turbine wheels under varying weather conditions, especially as regards direction and velocity of winds, warrants the conclusion that in the type of construction with which we were concerned, air distribution is seriously interfered with by conditions for which the plenum system, as generally installed, is not responsible.

The Experimental Room.

The first constructive effort in the ventilation of a schoolroom in which the plenum system had been installed was made in one of the regular schoolrooms of the Chicago

Normal College. The schoolroom was fitted up as an experimental room. One of the factors considered in the selection of the experimental room was that of subjecting it to our northwest winter winds.

The experimental room is 24 by 32 feet, on the basement floor, and has a west exposure. The room originally had a thirteen-foot ceiling. In the original installation for ventilation, air entered the room near the ceiling at the center of the east wall. The main air current was across the room from the east wall to the west (outside) wall, then down the cold outside wall, and back to the outlet duct near the floor in the east wall. The changes made in the room were as follows: First, the outlet duct, near the floor, was closed; then an airtight false floor was built about eighteen inches above the regular floor of the room, and a false ceiling was hung about eight inches below the room ceiling; then an air shaft was constructed to connect the inlet duct of the original installation with the air reservoir between the floors. (See Plates 1 and 2, pages 85 and 86.)

Outlet duct was tapped near the ceiling connecting it with the compartment between the ceiling and the false ceiling. Three-inch circular holes were cut through the false floor, and galvanized iron pipes, fitted into these openings, led under each desk to within an inch of the desk bottom. Openings also were made through the false ceiling so that air delivered into the room might move on through it. It will be noted that these changes turned the operation of the plenum system upside down. Instead of the air entering at the ceiling and leaving near the floor line, this new scheme delivered the air below the floor, and outgoing currents left the room at the ceiling. As already intimated, the idea in this scheme was to furnish a positive distribution of air to all the pupils within a room, and also to take advantage of the heat liberated by them in the production of upward moving currents. The new installation was tested in two ways: (1) Simple tests were made with anemometers placed at the edges of the desks. Every test showed an up current. (2) A more striking test than the one with the anemometer, and one as fully convincing, or even more so, was a chemical test made with ammonia and an indicator

known as phenolphthalein. This chemical test was made as follows: Linen strings were stretched over the rows of desks at the height of the breathing zone for children seated at the desks. Upon these strings, at intervals of ten or twelve inches, were hung pieces of unsized paper made wet with an alcoholic solution of phenolphthalein. When the room was thus dotted over with these wet papers, it looked much like a laundry drying room flecked with white. Before the wet papers had time to dry, a handkerchief, made thoroughly wet with concentrated ammonia water, was hung in the air duct leading from the plenum chamber, or distributing room, to the experimental room. Within two minutes after hanging the handkerchief in the duct, every paper on the linen threads in the experimental room became red in color. When ammonia is added to a colorless solution of phenolphthalein, the solution becomes red; therefore, the change in the color of the papers was conclusive evidence that ammonia from the handkerchief had been distributed to every piece of paper wet with the alcoholic solution. The test was repeated at another time with the same result. Still another test was made which contained an added feature. In addition to the papers supended in the breathing zone over the desks and seats, others were hung on strings stretched parallel with those over the rows of desks about seven feet from the floor, but directly over the aisles. In this test all the lower papers reddened in approximately the same time as before, and the upper ones reddened soon thereafter. These tests are conclusive evidence that the air in the experimental room is delivered to each desk, and that the movement of the air in the room is upward, and quite uniformly so. Moreover, anemometer tests made at the outlets of the galvanized iron tubes before the desks were placed, showed that each tube delivers approximately the same volume of air in unit time.

The Experimental Room Becomes a High School Room.

As soon as the before-mentioned changes in the experimental room had been made and tested, the room became a regular high-school room, in use throughout the day. It is

customary for classes to change rooms for different recitations, and, therefore, the experimental room was occupied by different classes each hour. This arrangement added somewhat to the difficulty of our experiments.

A Requirement for Ventilation.

However satisfactory the quantity of air furnished for the ventilation of a room, and however satisfactory may be the means employed for properly distributing it, both of which in the long run are very important, nevertheless the human body makes an immediate demand which may overshadow either or both. Immediate physical comfort is the standard of the human body, whatever the consequences, as exemplified either in the drowsy stupor that descends on one immersed in a hot, stifling atmosphere on a cold wintry night, or in the quiet repose that comes from a balmy summer breeze outdoors. Good ventilation shall produce immediate comfort.

One of the most prominent as well as immediate factors in the production of comfort, is temperature, and therefore a study was made to determine the best temperature for a schoolroom. The comfort of the human body is largely influenced by the temperature of the surrounding air, and also, and at the same time, by the rate at which perspiration may evaporate into the air from the body. Relative humidity influences the rate at which such evaporation occurs, but it is only in recent years that much consideration has been given to atmospheric humidity in relation to temperature and comfort.

Temperature and Humidity in Relation to Comfort.

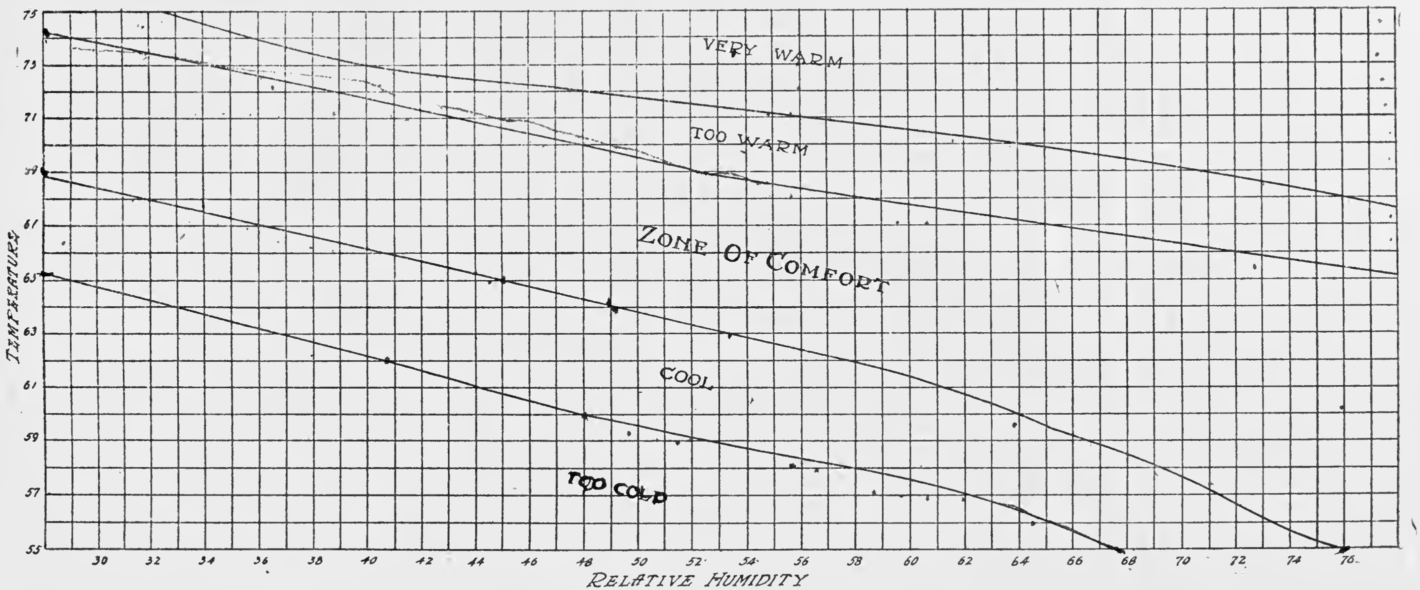
It has become traditional in this country that the best temperature to maintain in a room is 68 to 70 degrees. There are, however, some who urge that these temperatures are too high, and they cite the English practice of 59 to 62 degrees as evidence of their claim. The difficulty with both these positions is that in deciding on the best temperature, proper consideration is not given to relative humidity. Any

adult knows that sultry days are much less comfortable than days of even higher temperature when the atmosphere is comparatively dry. This well-known fact of outdoor experience must be taken into account, especially since it is now recognized that in cold weather we need to humidify air indoors. On this point of humidity, it may be said that the human organism seems to be adapted to a large range of relative humidity, but it is not accustomed to abrupt changes such as one might experience on a cold day in passing from the outdoors into a heated room. In a word, it seems important from the standpoint of health and comfort to maintain a fair degree of correspondence between the relative humidity of outdoors and indoors.

Any system of ventilation, to be practicable, must produce a feeling of comfort, and therefore both the temperature and the relative humidity of the air are important in ventilation. Temperature and relative humidity jointly help determine comfort.

It has generally been considered that a temperature of from 68 to 70 degrees with a relative humidity of 70 per cent, is a most desirable condition to obtain (the 70 per cent relative humidity also is largely traditional). In our tests it was assumed that the best temperature may or may not be 68 to 70 degrees; and also the most satisfactory relative humidity may or may not be 70 per cent.

The experimental room was equipped with an automatic temperature control, and also an automatic humidity control. Moreover, the temperature in the different parts of the room was determined by means of a sling psychrometer. For the most part, the tests on relative humidity and temperature in relation to comfort, were made by a member of the Commission and a graduate student from the University of Chicago. Frequently individual high school pupils in the room were asked whether or not they felt comfortable, and in each case the pupil answering did not know that any other pupil had been asked. The teachers in charge of the room also were asked for opinions. All these opinions, together with our own, served as a basis for record.



Comfort Zone Chart (see page 48).

Comfort Zone.

(See Chart, page 47.)

Before working very long, it became evident that there was a temperature and humidity range within which the occupants of the rooms were comfortable, and this range gave rise to what is called the Comfort Zone. This term, comfort zone, means that there is a maximum temperature with a minimum relative humidity, and minimum temperature with a corresponding maximum relative humidity between which limits the occupants of a room are comfortable. In other words, there seems to be no best temperature and also no best relative humidity; but the maximum temperature at which one is comfortable will be associated with a minimum relative humidity, and the minimum temperature for comfort will have associated with it a maximum relative humidity. Under the conditions with which we were working, we found that a temperature of 64 to 70 degrees with a corresponding relative humidity of 55 to 30 per cent, seems to be the limits; that is, the comfort zone for us was between 64 degrees and 55 per cent and 70 degrees and 30 per cent.

It is worthy of note that with a temperature below 67 or 68, with a proper relative humidity, the pupils were better able to give attention to their work than if the conditions were otherwise.

Outside Wall and Window Chill.

The problem of how to prevent outside wall and window chill from seriously interfering with ventilation, has never been satisfactorily solved.

With the change in installation in the experimental room, it was necessary to make some provision for preventing a sheet of cold air from falling down the exposed walls and windows. We tried to do this by installing steam pipes along the window casings just in front of the windows. The idea in this installation was to induce convection currents around the windows, and in this way prevent the downward currents of cold air. Tests were made of the scheme in two ways: (1) By the use of the small turbines it was found

that down currents of air were established from a few inches to a foot or more above the horizontal steam pipes. A second method was that of getting temperature readings at different heights from the floor in the aisles between the desks and the outside wall. These temperature readings showed a variation from almost nothing to eight or ten degrees, between the floor and the top of the desks. During the very severe weather of January and February, 1912, it became evident that this installation was only partially satisfactory. When the outside temperature was ten or more degrees below zero, there was a cold current of air that spilled out from the window over the top of the heating pipes above the window sills. This fact led to a proposed installation to overcome the window chill in another way—by means of a sheet of hot air. This new installation will be tried during the coming winter.

Ventilating and Heating Combined.

The plenum system with which we have worked combines the heating and the ventilating of a building. The heating is accomplished by means of hot air which also is used subsequently for ventilation.

Insulated Buildings.

Too much importance cannot be placed on the quality of construction in a building in its relation to the efficiency of the ventilating system. This is particularly true with reference to installation. In the usual type of building construction, it is sometimes necessary, in order to heat the building properly, to introduce more air than is required for ventilation. The other alternative might be to introduce the air at an unduly high temperature, but this procedure is always objectionable because of its effect upon the comfort of the occupants. When separate means of heating the building are provided, as with direct radiation, there is a tendency to operate the plant without ventilation. In general, the lower it is possible to maintain the temperature of the incoming air, without discomfort, the

better are the results with reference to ventilation. From the standpoint of economy, it is always desirable to introduce no greater volume of air than is actually required for ventilating purposes.

Our Latest Installation.

Our first attempt at insuring an equitable distribution of air for ventilation purposes within the experimental room led us to a more permanent installation. In the new installation, we have separated the heating of the experimental room from the ventilating, in so far as they seem to impair the efficiency of each other. The scheme in brief consists in bringing the air for ventilating purposes into the room through galvanized iron ducts insulated with asbestos and located under the false floor. This system of ducts terminates in three-inch iron pipes securely fastened to the floor and leading up under the desks. The room is heated by means of hot air driven under the floor. The idea in this scheme is to warm the floor. In order to reduce the effect of window chill, double windows are to be installed, and the heated air from under the floor will be forced upward between the two sets of windows and thus effectually overcome window chill. As in the older installation, the air comes in below the desks and leaves the room through twelve registers in the false ceiling. The air used for ventilating, being introduced through separate insulated ducts, may be at a much lower temperature than that of the air used for heating.

Report of Test Made by the Chicago Commission on Ventilation

At the Office of

Joseph T. Ryerson & Son, Chicago, Ill.

April 9, 1914

(See Plans, pages 52 and 53.)

Type.

General office, consisting of the entire top floor (3rd) of the building. This is divided into one very large room, with a few adjacent smaller private offices. The large room has many low partitions, counters, etc. The ceiling is largely of glass under a sawtooth type skylight.

Number of Occupants.

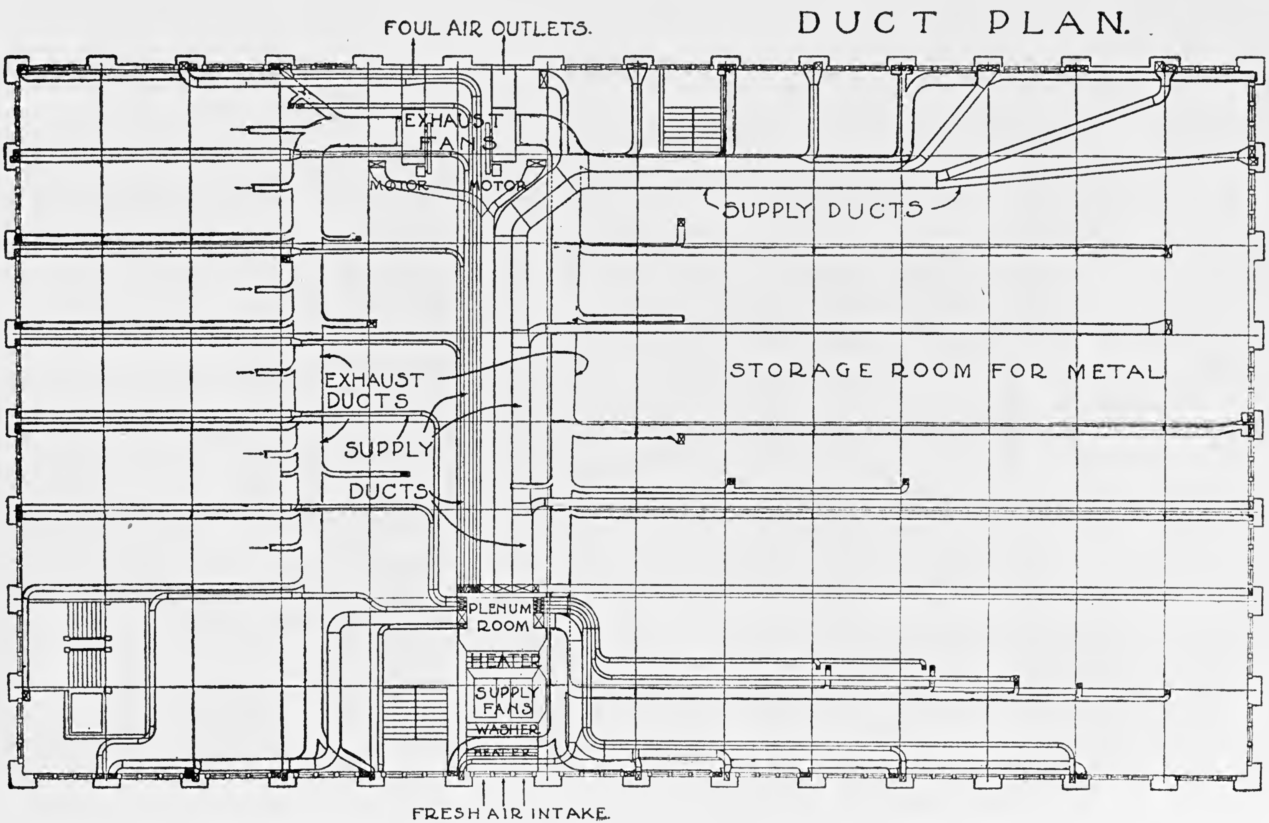
Normally about 235.

System of Heating.

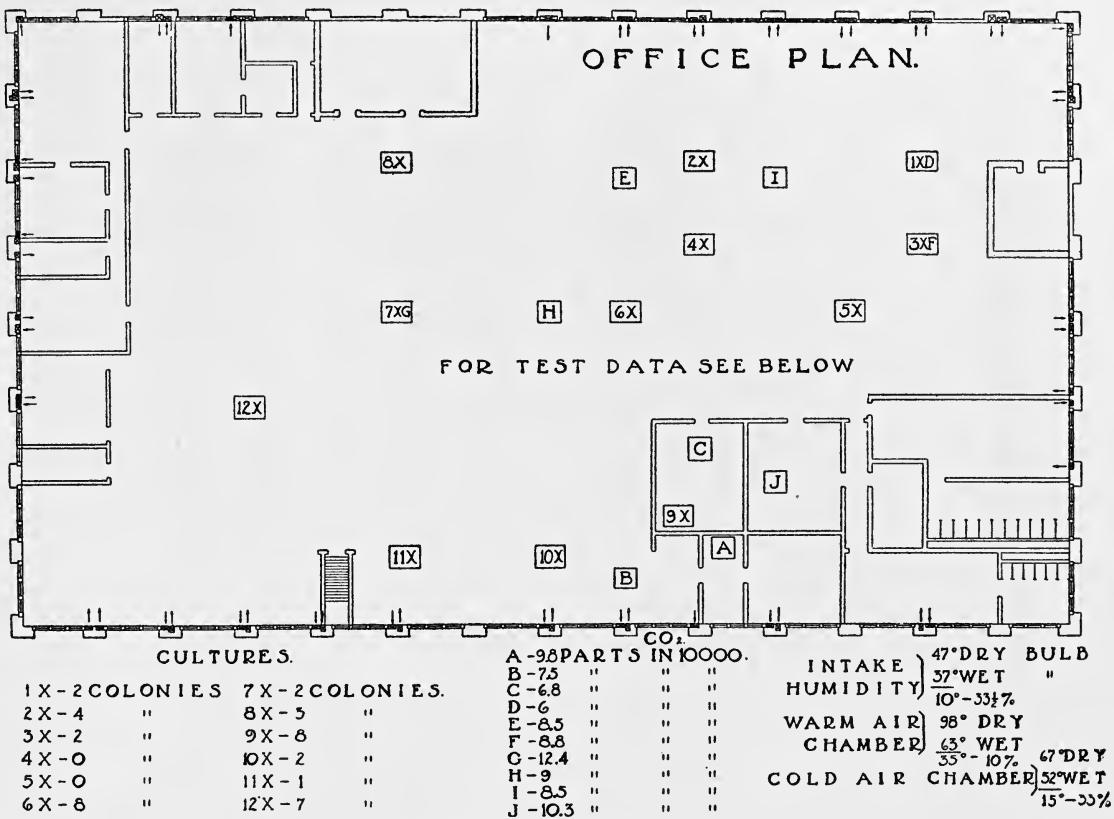
Entirely indirect steam with both supply and exhaust fans, with air washer and automatic temperature control.

System of Ventilation.

By dilution. The inlet openings are about 8 feet above the floor on the outside walls, averaging about 20 feet apart. The outlet openings are at the floor, in the outside walls and parallel with the inlet openings. Ducts connect the various supply and exhaust flues with the fans, being run, of sheet metal, along the ceiling of the partially heated metal warehouse under the office.



Ducts and Apparatus Under Office Floor.



Main Floor, Plan.

Supply Fans.

Two double wide double inlet full housed 8-blade fans, changed, evidently after the original installation, by adding 8 blades about 6 inches wide alternating with the original blades.

The fan wheels are 42 inches in diameter and about 42 inches wide at the periphery. Both are on the same shaft and are operated at 292 R. P. M. Were they of the 8-blade type, they should deliver 22,000 cubic feet of air per minute at this speed. They are delivering, by anemometer test of the tempered air which they handle, about 27,000 C. F. M. This increase is accounted for by the extra blades. The fans are belt driven by a 15-horsepower motor.

Exhaust Fans.

These have a rated capacity of about 80 per cent of the capacity of the supply fans and discharge the air exhausted from the office into a storage shed.

Intakes.

Cold air is drawn from three windows, each 4 feet by 4 feet 6 inches, about 30 feet above the street. The room inlet openings have horizontal blade diffusers installed by the owner after having had experience with cold drafts.

Outlets.

The outlet openings from the rooms are in the side walls. Many are obstructed by furniture. There is no provision for any air removal at or near the ceiling.

Heater.

Eight rows of 1-inch pipe, controlled by diaphragm (thermostatic) valves, between the air washer and the intake.

Twelve rows of 1-inch pipe, automatically controlled, between the air washer and the fan.

Free area for air passage, 29.2 square feet.

Total surface 2,500 square feet.

Air Washer.

Multiple spray type, with automatic water line governor and electric driven belted centrifugal pump. The eliminators are vertical. No humidity control or means of heating the water is provided. The water was very dirty. The eliminator was coated with dry deposit, ⅛ to ½ inch deep. The washer is 13 feet wide, 6 feet high, and 5 feet paralleling the direction of the air passage.

Ducts.

Ducts are of sheet metal, have very long runs, and are figured for 800 to 1,500 lineal feet per minute velocity. They are not insulated from each other or from the surrounding air, which often gets as low as 30 degrees. As the ducts are rather minutely subdivided, with separate automatic mixing dampers in each, the skin friction is considerable.

Plenum Chamber.

There are no heating coils between the air washer and the fan, and the tempered air used for cooling the office evidently is often insufficiently heated. By means of double dampers and a complicated series of baffles between the tempered air and hot air chambers, an attempt has been made to warm the tempered air by forcing hot air to mix with it, under thermostatic control.

Time of Test.

2 to 5 P. M.

Temperatures.

Outside air, plus 37 deg. F.
At air washer, plus 46 deg. F.
Air washer water, plus 46 deg. F.
Hot air chamber, plus 98 deg. F.
Tempered air chamber, plus 67 deg. F.
In the office, average, plus 72.2, ranging from plus 68 to plus 76 deg. F.

Relative Humidity.

Relative humidity outside, 33.5 per cent.

Average in the office, 38.4 per cent, ranging from 26 per cent up to 50 per cent.

Bacteria.

Petrie dishes were exposed for two minutes each at the points marked "1X, 2X," etc., on the plans, with the results shown on the margin, following the index numbers.

Air Distribution.

A. Samples of the air were taken at the points marked "A, B," etc., on the plans, with the results shown on the margin, following the index numbers. The outside CO_2 at the beginning of the tests was 3.8 parts per 10,000.

B. Ammonium chloride formed from the combination of ammonia and hydrochloric acid was introduced into the plenum chamber, to visualize the air distribution.

Dust.

The dust content in the entering air at the supply windows was 5,600,000 per cubic centimeter. Between the washer and the fans it was 4,000,000 per cubic centimeter. In the office, it was 1,600,000 as tested at two representative points.

Discussion.

The plant has been in use about five years. The tempering coils, being exposed to the weather are very rusty. Several pipes, having frozen, are blanked off. The washer is very dirty.

The fan wheels and housings are covered with oil and dust averaging ¼ inch deep. The plenum chamber and ducts are very rusty. The plant otherwise is in good order. There is considerable discoloration of the walls around the room intakes. The neighborhood of the plant is smoky and dirty.

The average relative humidity was lower than would be desirable, and if an average of 45 per cent had been maintained, greater comfort and a lower temperature would be possible.

The bacteria colonies were very low in number, indicating excellent cleaning in the room, and an ability in the plant to maintain a high efficiency in this regard.

The carbon dioxide analysis indicates a very poor fresh air distribution, as where it showed by this index 12 parts of CO_2 per 10,000 only 750 cubic feet of air per hour per occupant were being delivered in such localities. For the whole room nearly 6,900 cubic feet of air per hour per occupant are really delivered.

The air distribution test showed that the greater part of the fresh air supply is being delivered to the north side of the room. The adjustment of the volume dampers which effected this evidently was made in order to warm the room in cold weather, this being especially necessary since the heating plant is on the south, and the supply ducts are run long distances in a very cold place without insulation.

The high dust content at the inlet and the low dust count in the room are striking, especially as the air washer seems to have an efficiency of but 28 per cent.

It may be accounted for by the disturbance of local settled-out dust in the intake and fan rooms by the operatives of the instruments and by the fact that much of the

dust so stirred up settled in the fans and ducts before reaching the room.

Conclusions.

The owner evidently made and is making a conscientious endeavor to provide the best possible working conditions. The provision of some direct radiation along the north side, or indirect radiator boosters in the ducts running to the north side, by enabling the room to be heated evenly would permit of a more perfect air distribution, correcting the condition indicated by the CO_2 and air distribution tests. The trouble would be ameliorated by heating the room under the office, or by insulating the ducts.

The supply fans are running very slowly in consideration of the length of the ducts and there is ample power to speed them up to at least 350 R. P. M. The entire air handling mechanism should be thoroughly cleaned at frequent intervals.

The installation of automatic humidity control is not difficult, and would improve the conditions.

The closing of the inlet openings on one side of the room and the closing of all vent openings on the opposite side is suggested for use in warm weather especially, as it is believed that such a procedure would insure a more thorough sweeping with fresh air of the entire area.

For hot weather operation, it would probably be an improvement if ceiling outlets were provided, whereby the hot air accumulating there by reason of the sun effect could be forced directly out by the incoming cooler air.

Deductions.

A similar new plant should be so designed that there will be no long ducts run in cold air, especially to the north side. It should have its vertical flues thoroughly insulated, especially if they must run up outside walls. It should have both floor and ceiling inlets and outlets so that efficient summer operation may be effected.

Instruments.

The various instruments used in this test are described in the appendix, pages 70 to 83.

CHICAGO COMMISSION ON VENTILATION
CABINET TEST REPORT

NUMBER 4 DATE JAN. 10, 1914

SUBJECT	SEX	AGE	WEIGHT	HEIGHT	TYPE	OCCUPATION
MR. DAVIS	MALE	50	175	5'-6"	MEDIUM	MGR. VENTO DEPT. A.R.CO.
MR. HART	MALE	35	170	5'-11"	DARK	H.&V. ENGINEER

PRESENT CONDITION

BOTH SUBJECTS IN GOOD HEALTH. FREE FROM ANY ORGANIC DESEASE

REMARKS TEST WITH TWO OCCUPANTS IN CABINET FOR 1 HR. & 40 MIN.
AIR WAS NOT CHANGED, CHEMICALLY TREATED, OR DEHUMIDIFIED.

	BEFORE ENTERING	1ST. PERIOD	2ND. PERIOD	3RD. PERIOD	4TH. PERIOD	5TH. PERIOD	6TH. PERIOD	7TH. PERIOD	8TH. PERIOD
HOUR	2:20	2:23	2:45	3:00	3:15	3:30	3:40	4:00	
C.F.M.	80								
APPEARANCE	NORMAL	NORMAL	NORMAL	FLUSHED	FLUSHED & WARM		FLUSHED & PERSPIRING		
HOW OCCUPIED	CARDS	CARDS	GAME NOT INTERESTING						
PULSE	72-73						84-92	86-84	
RESPIRATION	16-17		18-20				FAST		
BLOOD PRESSURE									
TEMPERATURE TOP D.	69		77	80	81	83	83		
" " O.	70		78	80	83	84	84		
" BOTTOM D.	68		78	80	80	80	81		
" " O.	68		79	80	80	81	81		
CO_2	14		64	96.5	115	149		225	
OXYGEN									
NITROGEN									
OZONE									
OTHER									
BACTERIA		7-5M.	6-5M.		2-5M.				
DUST	NONE								
RELATIVE HUM. %	28	49	62	70.5		75		92	
WET BULB	52	65.5	70	73		75		78	
DRY BULB	69	78	80	81		83		82	

REMARKS THE TEMPERATURE OF BOTH OCCUPANTS OF THE CABINET REMAINED NORMAL THRUOUT THE ENTIRE EXPERIMENT. AT 3:40 IT WAS NOTED THAT THE FACES OF THE OCCUPANTS WERE FLUSHED AND BEADED WITH PERSPIRATION. MR. DAVIS' FACE WAS DRAWN AS THOUGH SUFFERING. AT THE COMPLETION OF THE EXPERIMENT MR HART COMPLAINED OF A SLIGHT HEADACHE AND OF FEELING SOMEWHAT WEAK. MR. DAVIS STATED THAT HE DID NOT FEEL RIGHT, BUT COMPLAINED OF NO OTHER SYMPTOMS.

Cabinet Tests

(See Plate 3, page 86.)

A series of cabinet tests is being conducted by the Commission under varying air conditions, with particular reference to volume, movement, temperature, humidity, carbon dioxide, dust and bacteria. It is the intention to repeat these tests with subjects of different types.

The cabinet, which is shown in the accompanying illustration, is built of heavy galvanized iron, 28 inches wide, 6 feet long, and 6 feet high. All seams are soldered and painted. On one side are two observation windows, each 2 feet square. At one end is an air tight door, and at the other end is a three-speed direct connected Sirocco fan, having a maximum capacity of 84 C. F. M. The installation of the fan is such that the air may be re-circulated in the cabinet, or fresh air introduced. The fan discharges the air into the cabinet through either or both of two compartments in which chemicals or other material may be placed for controlling the temperature, humidity, CO_2, etc. In addition to the above a small air washer is about to be installed.

The cabinet easily accommodates two persons. The tests are usually conducted with two subjects of different age and type, at the same time, in order to obtain a check on the effects noted.

Observations are taken, at stated periods throughout the tests, of the air conditions as well as the physical and mental condition of the subjects.

The tests thus far have been only of a preliminary nature, to enable us to determine the best method of conducting them, and also to determine the best apparatus required to maintain the desired atmospheric conditions.

Five of these tests have been made, ranging from one to three hour periods and an illustration of one of the test sheets is given herein.

Revised List of Resolutions of the Chicago Committee on Ventilation

November, 1913

1. Resolved, That carbon dioxide, as encountered in working practice is not the harmful agent of major importance in expired air or air otherwise contaminated.

2. Resolved, That a temperature of 68 deg. F. with a proper relative humidity is the proper maximum temperature for living rooms artificially heated.

3. Resolved, That in the present state of knowledge, it is impossible to designate all harmful factors in or associated with expired air.

4. Resolved, That the principle of ventilation by currents is preferable to the principle of ventilation by dilution.

5. Resolved, That for adequate ventilation, smaller volumes of air suffice when introduced by currents than when introduced by dilution.

6. Resolved, That ventilation which utilizes the principle of convection in producing currents is more effective and economical than that which neglects this principle.

7. Resolved, That upward ventilating currents in crowded rooms are desirable, provided the sources of air supply are free from contamination.

8. Resolved, That in making use of upward ventilation, attention should be given to the counteracting of wall and window chill.

9. Resolved, That in those processes of manufacture where considerable CO_2 is liberated, the CO_2 content is not a proper index of air pollution.

10. Resolved, That for the removal of kitchen odors, body odors, stable odors, and other odors associated with heat production, upward ventilation is more efficient than downward ventilation.

11. Resolved, That the delivery of a certain volume of air per unit of time, per occupant, into a given space does not necessarily constitute ventilation.

12. Resolved, That air which is introduced into an occupied room in such a way that it strikes the occupants should be not lower in temperature than 60 deg. F.

13. Resolved, That heating and ventilating are two distinct problems, and therefore, the installation of heating and ventilating systems, whether separate or combined, should be such that neither system shall interfere with the efficiency of the other.

14. Resolved, That from the standpoint of health, relative humidity is one of the important factors in ventilation.

15. Resolved, That efficient air cleaning devices are desirable in all ventilating installations where the air supply is liable to be contaminated by dust, or other objectionable matter.

16. Resolved, That the bacterial content of the air is an important factor in all ventilation, and bears a direct relation to the source and quantity of air supply.

Car Ventilation.

Street Cars.

17. Resolved, That ventilation by deck sash is never satisfactory in street cars.

18. Resolved, That either the plenum or the vacuum principle of ventilation is applicable to the ventilation of street cars.

19. Resolved, That air inlets should be of such size and location that drafts are not perceptible when the air enters at a temperature of from 50 to 60 deg. F.; and they should be of such number and distribution as to supply the maximum number of occupants with the proper amount of air.

20. Resolved, That in street car ventilation, the use of a plenum system without outlets, or an exhaust system without inlets is not compatible with a high degree of efficiency.

21. Resolved, That air delivered into street cars should be not colder than 50 deg. F.

22. Resolved, That in street cars in which wraps are worn, a temperature of not less than 50 deg. F. or more than 60 deg. F. should be maintained during artificial heating.

Elevated Cars.

23. Resolved, That ventilation by the deck sash is never satisfactory in elevated cars.

24. Resolved, That either the plenum or vacuum principle of ventilation is applicable to the ventilation of cars on elevated railways.

25. Resolved, That inlets should be of such size and location that drafts are not perceptible when the air enters at a temperature of from 50 to 60 deg. F.; and they should be of such number and distribution as to supply the maximum number of occupants with the proper amount of air.

26. Resolved, That in elevated car ventilation, the use of a plenum system without outlets or of an exhaust system without inlets is not compatible with a high degree of efficiency.

27. Resolved, That air delivered into elevated cars should not be colder than 50 deg. F.

28. Resolved, That in elevated cars, in which wraps are worn, a temperature of not less than 50 deg. F. or more than 60 deg. F. should be maintained during artificial heating.

Railroad Cars.—*Day Coaches, Sleeping Cars, Suburban Cars, and other Cars making long runs.*

29. Resolved, That ventilation by the deck sash alone is never satisfactory in railroad cars.

30. Resolved, That either the plenum or vacuum principle of ventilation is applicable to the ventilation of railroad cars.

31. Resolved, That inlets should be of such size and location that drafts are not perceptible when the air enters at a temperature of from 50 deg. to 60 deg. F.; and they should be of such number and distribution as to supply the maximum number of occupants with the proper amount of air.

32. Resolved, That in the ventilation of railroad cars, except sleeping cars, the use of a plenum system without outlets or of an exhaust system without inlets is not compatible with a high degree of efficiency.

33. Resolved, That air delivered into railroad cars should not be colder than 50 deg. F.

Standards.

34. Resolved, That the following standards should apply to the ventilation of cars:

Street cars, elevated cars, or other cars making frequent stops, during which the doors are opened, shall be so ventilated that the amount of air entering the car for ventilation, through openings provided for such purposes, shall be at the rate of not less than 500 cubic feet per hour, per occupant, based upon the maximum carrying capacity (seats and standing room included) of such car, provided that the total amount from all sources shall not be less than 750 cubic feet per hour.

Day coaches, sleeping cars, suburban cars, and other cars making long runs, shall be so ventilated that the amount of air entering the car for ventilation, through openings provided for such purpose, shall be at the rate of not less than one thousand (1,000) cubic feet per hour, per occupant, based upon the maximum seating capacity of such car.

Smoking cars and smoking compartments in cars shall be so ventilated that the amount of air introduced for ventilation shall be at least 20 per cent in excess of the amount required for the same type of car under the above standard.

35. Resolved, That the carbon dioxide content of the air of cars should not exceed ten parts by volume in each ten thousand (10,000) parts of air; provided that in street cars, elevated cars, and other cars used in local interurban service the carbon dioxide content may not rise above twelve parts by volume in each ten thousand (10,000) parts of air.

Picture Theaters.

36. Resolved, That in the ventilation of picture theaters provision must be made for warming and regulating the temperature of the air introduced.

37. Resolved, That when cold air for ventilation is introduced into picture theaters above the breathing zone, either

(1) There will be an insufficient supply of air for proper ventilation, or

(2) The occupants of the theater will be uncomfortably cold.

38. Resolved, That upward ventilation in picture theaters is more efficient than downward ventilation; also it is more economical from the standpoint of operation.

39. Resolved, That in the ventilation of picture theaters the fans and ducts should be designed for a pressure not exceeding, in normal cases, ¾ ounce per square inch.

40. Resolved, That in the ventilation of picture theaters in which furnace heating apparatus is used, the space between the furnace and its casing must be under air pressure at all times when the fan is in operation.

41. Resolved, That when furnace heating apparatus is used in the ventilation of picture theaters, the furnace must never be under suction when the fan is in operation.

42. Resolved, That in the downward ventilation of picture theaters, the room must be practically an air-tight enclosure above the breathing zone.

43. Resolved, That in the cooling of picture theaters in the summer time, the system of downward ventilation is inefficient.

44. Resolved, That air delivered into picture theaters for ventilation purposes should not be delivered at a temperature colder than 60 deg. F.

45. Resolved, That the temperature in picture theaters at the breathing zone should not be lower than 60 deg. F. nor higher than 70 deg. F.

46. Resolved, That in the breathing zone the number of colonies of bacteria on a standard agar plate should never exceed 15 for a five-minute exposure.

47. RESOLVED, That the carbon dioxide content of the air in the breathing zone in picture theaters should not exceed 10 parts per ten thousand.

48. RESOLVED, That the relative humidity of the air when brought into picture theaters for ventilation purposes should not be less than 35 per cent.

49. RESOLVED, That the velocity of the air delivered into picture theaters for ventilation purposes by upward ventilation shall not exceed 150 feet per minute.

50. RESOLVED, That the quantity of air delivered into picture theaters for ventilation purposes shall not be less than 25 cubic feet per occupant per minute. It shall be understood that in determining such quantity, the maximum seating capacity shall be considered as the number of occupants of the room.

51. RESOLVED, That fresh air registers in the floors of the aisles and lobbies of picture theaters should be prohibited.

52. RESOLVED, That both the design and location of fresh air inlets in picture theaters should be such as to minimize the possibility of contaminating them or the air which they deliver.

SCHOOL ROOMS.

53. RESOLVED, That either the plenum or vacuum principle is applicable to the ventilation of school rooms.

54. RESOLVED, That in the artificial ventilation of a school room, the air inlets and outlets should be of such size, number, and location as to insure equal distribution of air throughout the room.

55. RESOLVED, That the maximum temperature for a school room, artificially heated, should not be more than 68 deg. F.

56. RESOLVED, That the relative humidity of a school room, artificially heated, should not fall below 40 per cent.

57. RESOLVED, That in the present state of knowledge and practice the quantity of air supplied to school rooms for ventilation should not be less than 30 cubic feet per pupil per minute.

58. Resolved, That both the design and location of the air intake for a school building should be such as to minimize the possibility of contaminating the air supply.

59. Resolved, That efficient air cleaning devices are desirable in all ventilating installations where the air supply is liable to be contaminated by dust, or other objectionable matter.

60. Resolved, That in the automatic control of temperature within a school room, the thermostat should be so located as not to be influenced by wall chill. The thermostat should be so located as to be influenced by the average temperature of the room only.

61. Resolved, That in mechanically ventilated school buildings, it is desirable at stated periods to flush all the school rooms in the building with fresh air by means of open windows.

62. Resolved, That careful consideration should be given to the sweeping and cleaning of the school room as effecting its ventilation.

63. Resolved, That the temperature of a school room should be kept as low as the comfort of its occupants will permit; and that the temperature may be kept down by increasing the relative humidity.

64. Resolved, That in the proper ventilation of a school building in cold weather, it is necessary to provide means for humidifying the air introduced into the building. (See note.)

65. Resolved, That a constant temperature and a constant relative humidity are not conducive to the highest degree of comfort in a school room.

66. Resolved, That in the production of comfort for the occupants of a school room, the maximum temperature should be associated with a minimum relative humidity, and the minimum temperature should be associated with a maximum relative humidity.

67. Resolved, That in a school building artificially ventilated and heated the comfort zone should be established in order that the engineer may properly operate the heating and ventilating system.

68. Resolved, That the carbon dioxide content alone is not always an index of the contamination of air for ventilating purposes, within an enclosure.

Note: Relative humidity may be increased in a school room by means of properly muffled jets of steam introduced into the plenum or fan chambers from the boiler supply.

Methods and Devices Employed

This appendix describes the methods and devices employed by the Commission in making tests.

A—Air Velocities:
1. Anemometer.
2. Pitot Tube and Gauge.

Air Movements:
1. Ammonium Chloride Test.
2. Phenolphthalein Tests.
3. Balloon Tests.
4. Pin Wheel Tests.

Air Analyses (CO_2):
1. Method of Taking Samples.
2. Petterson-Palmquist Apparatus.

B—Bacteria:
1. Cultures.
2. Caldwell Tubes.
3. Sand Filters.

C—Cabinet Test Methods:
1. Sphygmomanometer.
2. Thermometers.
3. Psychrometers.
4. Air Samples.
5. Cultures.

D—Dust:
1. Sugar Filter.
2. Koniscope.
3. Aiken Portable Dust Counter.

E—Standard Candles.

A—Air Velocities.

The velocity of air or other gases may be measured directly by means of an anemometer, or indirectly by com-

puting the velocity from the differences in pressure that cause the flow, measured with the Pitot tube and gauge.

Anemometer.

(See Plate 4, page 87.)

The Biram pattern anemometer consists of a small wheel carrying 8 vanes. The wheel is connected by suitable gearing to indicating hands on the dial and the instrument so calibrated that the revolutions of the vanes indicate the velocity of air in feet per unit of time. The wide divergence in the readings obtained by two persons with the same anemometer, under the same conditions, should not be attributed to inaccuracy of the instrument, but rather to ignorance or carelessness in its use.

The first requisite is that the instrument be in good repair and properly calibrated. The second is that the readings be accurately timed. The third is that the proper method of taking the readings be employed.

In taking readings at the register face the method of slowly moving the anemometer across the register or up and down as the case may be, is only mentioned to be condemned. The reading will be inaccurate except at those registers where the velocity is uniform throughout the entire area. In taking readings, where the velocity varies over different areas of the register face, it can readily be seen that in moving the instrument slowly across the face of the register the momentum acquired by the revolving vane over the areas of high velocity will cause it to continue to revolve at a much higher rate than it should while passing over the areas of low velocity, consequently a higher average velocity reading will be obtained than the conditions warrant. The proper method is to divide the face of the register or other opening into equal areas of approximately 6 inches, and take one-half or one minute readings at the center of each square. The average of the total number of readings times the area of the opening will give the cubic feet of air delivered.

Pitot Tube.

(See Plate 5, page 87.)

The velocity of air flowing through a given duct depends on the difference in pressure maintained between the entrance and outlet. It is necessary to consider this pressure as made up of two components: (1) that which is required to compensate or overcome the loss due to compression and frictional resistance (static pressure); (2) that which is necessary to move the volume of air at the given velocity (velocity pressure). The sum of the two is the total or dynamic pressure. The air velocity is determined from the formula $v = \sqrt{2\,g\,h}$, which transferred into terms of air becomes $v = 1096.5 \sqrt{\frac{P}{W}}$ where v is the velocity in feet per minute, P is the velocity pressure in inches of water, and W is the weight of one cubic foot of air at the given temperature.

As there is no way of determining the velocity pressure directly the total and static pressures must be determined and the latter subtracted from the former to obtain the velocity pressure. For making these determinations the Pitot Tube is the most satisfactory instrument from the standpoint of accuracy and convenience. The tube used by the Commission is of the American Blower type, 48 inches long with a tip 4½ inches long. The static openings are four in number, two on either side, and .02 of an inch in diameter. The static branch of the tube is on the forward or tip side and the total pressure branch at the rear.

The readings are taken on an Ellison draft gauge, the scale graduated to .01 of an inch. The gauge has been provided with a special head and leveling device to be used in connection with a level tripod. This makes a combination that is portable, can be set up in any location and leveled quickly and accurately. (See Plate 6, page 88.)

Air Movements.

The velocity and direction of air movements in auditoriums, school rooms, etc., are studied by means of the

ammonium chloride test, phenolphthalein indicators, small counterpoised balloons, and pin wheels.

(1) Ammonium Chloride Test:

When strong NH_4OH and HCl are volatilized and the two gases brought into contact, a chemical reaction results with the production of NH_4Cl. This ammonium chloride occurs in a very finely subdivided state, is distinctly visible as a white cloud, and does not readily settle out of the air. This is a valuable method of studying air currents visually.

The test is made by saturating large desk blotters with the two reagents, bringing them in close proximity, 6 or 8 inches from each other, and shaking the blotters gently. The ammonium chloride is liberated as a cloud in the manner described, usually at a fresh air intake. The course which it takes and the velocity of its travel are noted. With 100 cc of each of these reagents enough ammonium chloride can be produced to become visible throughout the auditorium of a moving picture theater in about five minutes. The following modification of this test is useful where local air currents are to be studied:

The ammonium hydroxide is placed in one of the small 125 cc bottles and the acid in another. By means of the air sampling bulb, air is driven through these two bottles simultaneously, and the finely divided ammonium chloride is formed at the nozzle of the apparatus. (See Plate 7, page 88.) With this apparatus, a dense white cloud of ammonium chloride may be produced in any locality desired and its course and velocity studied.

(2) Phenolphthalein Test: (See Plate 8, page 89.)

This test depends upon the reaction which occurs in a weak alcoholic solution of phenolphthalein when acted upon by a strong alkaline reagent. For this test Soxhlet extraction shells are suspended by strings from wires at various points throughout the room where test is being conducted. A pledget of absorbent cotton saturated with distilled water is placed in the shell. The outside is saturated with a ½ per cent solution of phenolphthalein in 60 per cent alcohol. Strong ammonium hydroxide is then volatilized at the fresh air intake and the time when the reaction at various sta-

tions is observed, noted. This gives us a method of determining the time required for the air supply to reach the various locations where the indicators are placed.

(3) Balloon Test:

Small toy balloons are inflated with hydrogen gas and counterpoised with small improvised weights. These weights are just sufficient to keep the balloons in the air at the temperature in which the test is being made. They are liberated at various points and give a very interesting visual demonstration of air travel and the action of air currents. As the balloons become less buoyant some of the counterpoising weight is removed.

(4) Pin Wheel Test:

During the experimental work at the Chicago Normal College, Professor Shepherd devised these pin wheels for testing vertical air currents, especially the effect produced on the movements of air in a room by wall and window chill. The pin wheel is constructed of very light aluminum foil fastened into a cork hub, and balanced on a fine cambric needle thrust into cork or other suitable substance to form a base. A thin glass pivot made by drawing glass tubing may be used instead of the needle. These little devices are so delicate that the air currents produced from the heat of the experimentor's hand will cause the wheel to revolve.

Air Analyses.

(1) Sampling Device: (See Plate 9, page 89.)

After experimenting with various methods of taking air samples for CO_2 analysis the following has been adopted:

The apparatus consists of a clean rubber stoppered bottle of about 120 cc capacity, a Paquelin cautery bulb and 24 inches of tubing. The apparatus is held at arm's length from the body, great care being exercised that the expired air from the observer's mouth does not contaminate the samples. The cork is removed and the tube inserted to the bottom of the bottle. The tube is closed by pressing it between the thumb and the neck of the bottle and the bulb is compressed until the reservoir is distended. The thumb pressure is then released and the air in the reservoir allowed

to rush into the bottle, displacing the residual air. This operation is repeated three times in order to be sure that all of the air originally in the bottle and apparatus has been replaced by the air to be sampled. The tube is then removed, the bottle corked and sealed and taken to the laboratory for analyses.

(2) Analyses of Air Samples: (See Plate 10, page 90.)

Analyses are made for carbon dioxide with the modified Petterson-Palmquist apparatus. This consists essentially of a manometer (A) for obtaining similar pressure conditions at the beginning and end of the analyses; an absorption chamber (B) for removing the carbon dioxide in the sample, by means of potassium hydroxide; and a graduated scale (E) for reading the volume of the sample before and after the carbon dioxide has been removed.

The absorption chamber with its potassium hydroxide chamber, the bulb of the pipette, and the pressure compensating chamber, are all enclosed in a glass case and submerged in water to prevent slight changes in the temperature of the room from effecting the air under analysis. By means of an air bulb and a short piece of glass tubing, the water in this chamber is continually kept in motion during the analysis.

The procedure is as follows: (See Plates 11 and 12, pages 91 and 92.)

In analyzing a sample the mercury cup "F" is raised until the mercury fills the bulb of the pipette "D," the bottle containing the sample of air is now connected to "O" by a piece of rubber tubing, "N" being open; the mercury cup is lowered until the mercury rests at zero. This draws the sample of air into the bulb of the pipette, which holds 25 cc. Salt water is allowed to flow into the air sample bottle to replace the air which is drawn into the apparatus. The stop cock "N" is now closed, "P" opened and the location of the bubble in the manometer recorded. "P" is now closed and "M" opened. By lifting the mercury cup the air is now driven over into the absorption chamber "B," the bulb again lowered and the air is returned to the pipette. This is repeated three times when all of the carbon dioxide in the sample will have been

absorbed. The air is now brought back into the pipette and the mercury column lowered until the potassium hydroxide stands at exactly the same level it did at the beginning of the analysis. The stop cock "M" is now closed and "P" opened and by means of the pressure thumb screw "G," the pressure is increased or reduced until the manometer bubble registers the same pressure that it did before the carbon dioxide was removed from the sample. This completes the analysis, the reduction in volume being read directly on the graduated scale in parts of CO_2 per 10,000 parts of air.

B—Bacteria.

(1) Cultures: (See Plate 13, page 93.)

Agar plates are made by pouring 10 cc of agar, made according to the formula set as standard by the American Public Health Association for water and milk analyses, into Petrie dishes 10 centimeters in diameter. These plates are exposed 5 or 10 minutes in theaters and 2 minutes in street cars. They are incubated for 48 hours at room temperature and the colonies which develop, counted. A quantitative count has been made in some instances by means of a tube recently devised by Dr. Caldwell of the Municipal Laboratories. This is a galvanized iron tube 13 inches long and about 3½ inches in diameter, capped at both ends. The tube is of such dimensions that its capacity is exactly 2 liters. In taking a sample of air the caps from both ends are removed, the tube passed through the air by a horizontal motion until the observer is confident that all the air in the tube has been replaced by the air in the room. The upper cap, is now replaced and the tube inverted over an uncovered Petrie dish and allowed to stand for 20 minutes. At the end of this time, it has been determined experimentally that all of the bacteria in the tube will have settled on the plate, which is then incubated and the colonies counted. Enough work has not as yet been done with this apparatus to warrant a statement as to its accuracy; the indications are, however, that it will give, with some modifications, a simple method of making a quantitative determination of the bacteria in a unit volume of air.

(2) SAND FILTER: (See Plates 14 and 15, page 94.)

The apparatus for making quantitative bacterial determinations consists of the following:

A small gas meter is used for measuring the air. On the inlet of the meter a glass filter is fastened, as shown in the accompanying illustration. This filter contains sand to a depth of 1.5 centimeters, the sand being sifted through 100 mesh wire screen. Air is drawn through the meter by a high pressure centrifugal blower. From 10 to 50 cubic feet of air are usually drawn through the apparatus. The sand is shaken in sterile water and allowed to settle. A measured portion of the water is plated in agar, incubated and the number of colonies counted.

C—CABINET TEST METHODS.

(1) BLOOD PRESSURE (SPHYGMOMANOMETER): See Plates 16 and 17, page 95.)

For determining blood pressures in cabinet test experiments, a diaphragm dial Sphygmomanometer is used. The manometer proper consists of two free connecting air chambers, the diaphragm of one being so connected to the needle on the dial that changes of pressure are indicated directly in millimeters.

The pressure determining apparatus consists of a cloth covered rubber bag 9 inches long and 5 inches wide, provided with two short rubber tubes connecting with the interior. The bag is wrapped around the arm of the subject, the manometer attached to one of the tubes and the inflating bulb to the other. The bulb is also provided with a release valve so that the pressure in the sleeve may be reduced and accurately controlled.

In order to obtain a clear understanding of the use of this apparatus, it is necessary first to understand the principle on which it operates.

Each heart beat is composed of two parts, the systole or contraction, at which time the blood is forced out and into the arterial system, and the diastole, or expansion, when the heart relaxes and blood from the venous system re-enters the heart.

The resistance in the circulatory system is made up of friction of the blood passing through the vessels and the work performed in expanding them. This may be considered as the static pressure against which the heart operates.

The pressure recorded during the contraction of the heart is the highest and is, therefore, the maximum pressure.

METHOD OF USING: (See Plate 17, page 95.)

If now the rubber bag or sleeve is carefully adjusted on the arm of the subject and air pumped into the same until the pressure of the bag obliterates the pulse at the wrist, the pressure will be greater than the maximum pressure of the arterial system. With the release valve the pressure is now carefully reduced until the pulse is again just perceptible. At this point the dial indicates the maximum pressure of the arterial system in millimeters of mercury.

The pressure is now further reduced until every pulse beat is distinctly shown by the movement of the needle. At the point where the needle's excursion at each beat is the greatest will be the point of minimum pressure, corresponding to the resistance offered to the flow of blood by the circulatory system. The difference between the maximum and minimum pressure will be the pulse pressure or the surplus which the heart exerts above the resistance encountered. The maximum pressure in a normal adult male ranges from 105 to 145 millimeters. The normal minimum pressure ranges from 25 to 40 millimeters below the maximum. The normal pulse pressure ranges from 25 to 40 millimeters.

(2) TEMPERATURES:

These are taken with standard Fahrenheit thermometers graduated from —10 to +120 degrees at two locations at the floor line and two locations at the ceiling. One recording thermometer 3 feet above the floor line is used as a check on the other observations.

(3) PSYCHROMETER: (See Plate 18, page 96.)

The psychrometers used are of the standard sling pattern adopted by the United States Weather Bureau of the Department of Agriculture, illustrated herewith. In taking

readings, the wet bulb is thoroughly saturated and the instrument swung for fifteen or twenty seconds and a reading taken. The instrument is now swung again, the previous reading of the wet bulb being kept in mind. This operation is repeated until the wet bulb reaches the lowest point on the scale and begins to ascend, when the observations of the wet and dry bulb temperatures are recorded.

The relative humidity determinations are taken from a humidity chart prepared by the Carrier Air Conditioning Company of America.

(4) Air Samples:

Air samples are taken and analyzed for carbon dioxide according to the method described under appendix "A."

(5) Bacteria:

Cultures are taken as described under appendix "B."

D—Dust.

(1) Sugar Filter:

The filter for determining the amount of dust in a unit volume of air is described under appendix "B" for quantitative determinations of bacteria, except that sugar is substituted for sand in the filter. The filters are prepared as follows:

Twenty-five grams of sugar are used in the filter. This is sifted through a 25-mesh wire screen and again on a 100-mesh wire screen. The sugar used is that which is retained on the 100-mesh wire screen. Before beginning a test a large quantity of sugar is sifted and a control count made. After collecting the sample, the sugar is dissolved in 100 cc of distilled water, the water agitated and the sample placed in a Sedgwick-Rafter counting cell and the count made. (See Plate 19, page 97.)

The Sedgwick-Rafter counting cell is made by cementing a rectangular brass rim on an ordinary glass slide. The internal dimensions of the cell are: Length, 50 millimeters; width, 20 millimeters; and depth, 1 millimeter, giving it an area of 1,000 square millimeters, and a capacity of 1 cubic centimeter. A thick cover glass (No. 3) having dimensions the same as those of the outside of the brass rim forms the

roof of the cell. The cell and cover glass are thoroughly cleaned and the latter placed diagonally over the top of the cell, so that an opening is left at either end. One cc of the solution is now introduced by means of a small pipette at one side of the cover glass, the air escaping through the other. The glass is now turned to cover the cell, which is now ready for the count.

An ocular micrometer, consisting of a square, ruled upon a thin disc of glass, is placed upon the diaphragm of the ocular of the miscroscope. The square is of such size that with a certain combination of objectives (No. 3 Leitz) and ocular (No. 4 Leitz) and with a certain tube length of the miscroscope, the area covered by it on the stage is just 1 square millimeter. The large square is 1 square millimeter and with the ocular we have been using the small squares are 1/36 of a square millimeter.

The tube length was determined by comparison with the Thoma- Zeise blood counting cell. The cell filled with the solution is placed upon the microscope stage and the dust particles within a ruled square are counted in a number of representative fields. Inasmuch as some of the particles are light and rise to the top, while others are heavy and sink to the bottom, the focus of the microscope must be constantly changed to include all of these particles.

The number of dust particles in one cubic foot is then determined in the following manner:

Let A—represent total number of particles counted.
B—represent number of squares counted.
C—represent dilution of the sample.
D—represent number of cubic feet in sample.

$$\frac{A}{B} \text{ x } \frac{1,000}{D} = \text{number of dust particles in 1 cubic foot of air.}$$

Sources of Error:

1—Particles adhering to the filter.

2—Particles of dust in any of the apparatus used in the dilution water.

3—Disintegration of dust particles in the solution.

4—Presence of unnoticed dust in the objective or ocular or on the micrometer or the mirror of the microscope, or on the cover glass of the cell. The mirror

on the microscope and the glass cover are especially liable to gather dust, even during the progress of counting. To avoid errors control counts must be made on all samples of sugar and duplicate samples should be taken and counted, all apparatus carefully washed with soap and water and rinsed with distilled water. The count should be made as soon as possible after dissolving the sugar. The microscope must be carefully cleaned and the slide, mirror, and objectives examined from time to time during the progress of the count to see that they are free from dust.

(1) KONISCOPE: (See Plate 20, page 97.)

This is the original instrument devised by Professor John Aitken for determining the amount of dust in air. The principle on which it operates depends upon the well known physical fact that in saturated air, water condenses in minute droplets on every dust particle, if the dew point is lowered either by reducing the temperature or the pressure. The apparatus consists of an observation tube about 22 inches long provided with an eye piece at the proximal end, and an observation window at the distal end. The tube is lined with hygroscopic material throughout its entire length. Connected to the observation tube near the eye piece is a hand exhaust pump. At the other end of the tube a stop cock is provided for introducing the air to be sampled. In using the apparatus the hygroscopic lining is saturated with water. The stop cock is now open and by operating the pump, the air sample is drawn into the tube. The stop cock is now closed and by one or two quick movements of the piston the air in the tube is rarified, the dew point is consequently lowered, and a minute drop of moisture condenses on each dust particle, forming a dust fog or haze which is observed through the eye piece. The density and color of this fog is compared with a chart provided, which gives the relative amount of dust in the sample.

Owing to the personal element involved in the use of this apparatus its value is questionable, except where always used by the same person, and even then the results are only relative.

(3) Aitken Portable Dust Counter: (See Plate 21, page 98.)

Owing to the limited application of the Koniscope, for the reasons just enumerated, Professor Aitken has developed the principle of moisture condensing on the dust particles, when the dew point is lowered, in the design of his new machine. Instead of observing the density or color of the haze produced, the dust particles, with their attendant droplets of moisture, are precipitated on a ruled object glass and counted. If now a definite quantity of the air to be examined is saturated, and precipitation made the number of dust particles, with slight magnification, can be readily observed and counted.

This machine consists of a precipitation chamber with pump, filter, eye piece, etc., mounted on a tripod in a very convenient and portable manner. The precipitation chamber (a) holds exactly 50 cubic centimeters. The stop cocks (b and c) are bored and calibrated to hold ¼ and 1/20 of a cubic centimeter each. The chambers of these cocks are bored horizontally as well as vertically, so that air may be passed through from the filter, or a measured quantity introduced from the outside. These are situated between the filter (d) and the precipitation chamber. If these cocks are set longitudinally and the pump (e) operated, the air is drawn into the opening (o) through the filter and into the precipitation chamber. The pump piston is depressed 10 or 12 times in this manner, removing all of the residual air and dust in the apparatus.

Method of Operation:

The stop cocks (c and x) are closed and the pump piston depressed once. This slightly rarifies the air in the precipitation chamber. The three-way cock (b) is now turned horizontally and the bore filled with the air to be sampled, by means of the rubber tube (n). It is then turned vertically, the stop cock (x) opened and the negative pressure, caused by the previous depression of the pump piston, draws the air into the precipitation chamber. By means of the stirring rod (g) the sample is now mixed until the air is saturated. The stop cock (x) is closed and the pump piston again depressed. Looking through the eye piece (n)

a fine shower of rain is observed to fall on the ruled object glass, where the droplets are counted.

Noting the dilution of the sample and counting the number of dust particles in a given portion the total number of dust particles per cubic centimeter of air is calculated, the formula being as follows:

A—represents total number of particles counted.
B—represents total number of squares counted.
C—represents dilution of samples.

$\frac{A}{B} \times 100\,C =$ the number of dust particles per cubic centimeter.

If the upper stop cock is used C will be 200; if the lower is used C will be 1,000. As each square is one square millimeter in area and one centimeter high its cubic content is .01 of a cubic centimeter. C must, therefore, be multiplied by 100 to obtain the average number of particles per cubic centimeter.

A modification of the method, suggested by Mr. Hoskins is to insert a smoked cover glass on the ruled objective. The precipitation then makes a permanent record, which is removed and preserved. (See Plate 22, page 99.)

STANDARD CANDLES:

Candles employed in theater tests are of pure paraffin wax 1⅛ inches in diameter and 6 inches high. By careful test they decrease in weight 9.8 grams per hour. The heat units given off as determined by the bomb calorimeter gives 370 B. T. U. per hour. The amount of carbon dioxide produced is .48 of a cubic foot per hour. Each candle, therefore, very closely approximates the heat and carbon dioxide production of two adult persons, per unit of time.

Plate No. 1. Desk in Experimental School Room showing individual air supply. See page 43.

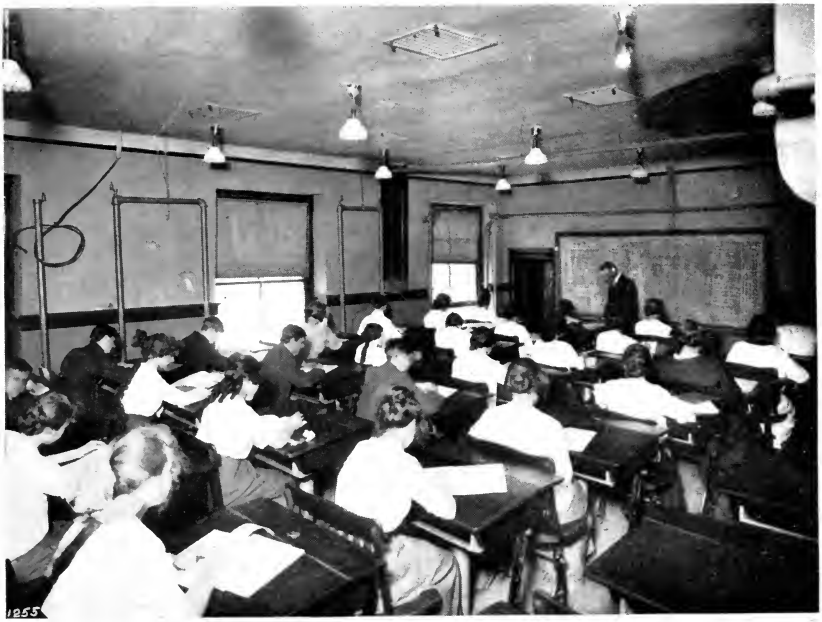


Plate No. 2. Experimental School Room. See page 43.

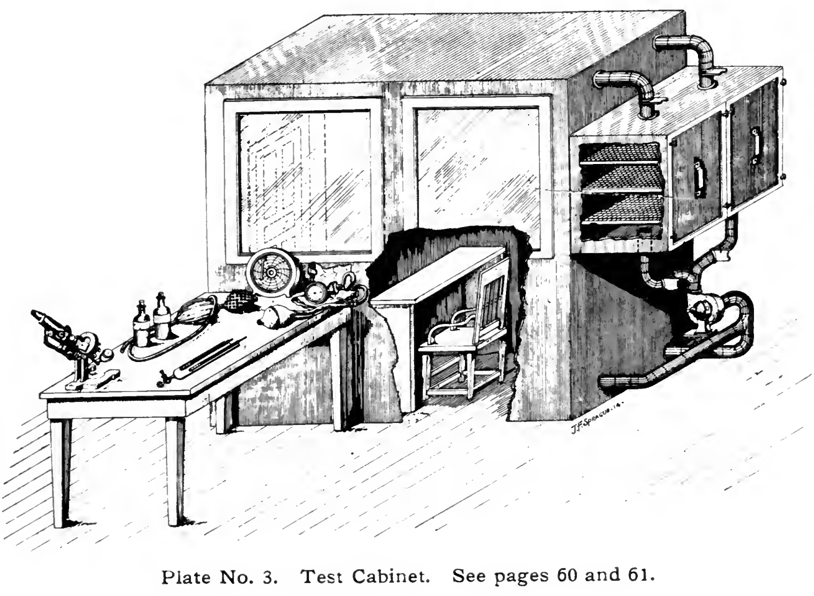


Plate No. 3. Test Cabinet. See pages 60 and 61.

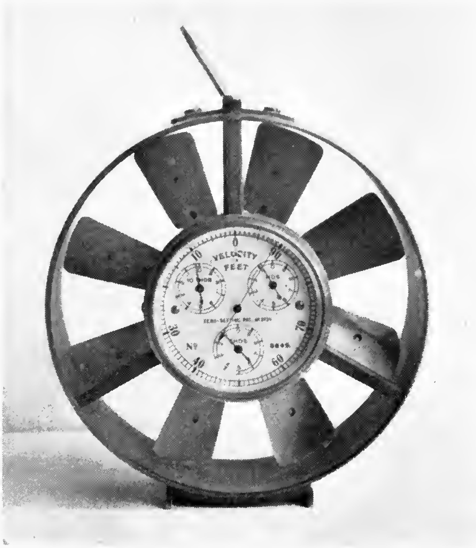


Plate No 4. Anemometer. See page 71.

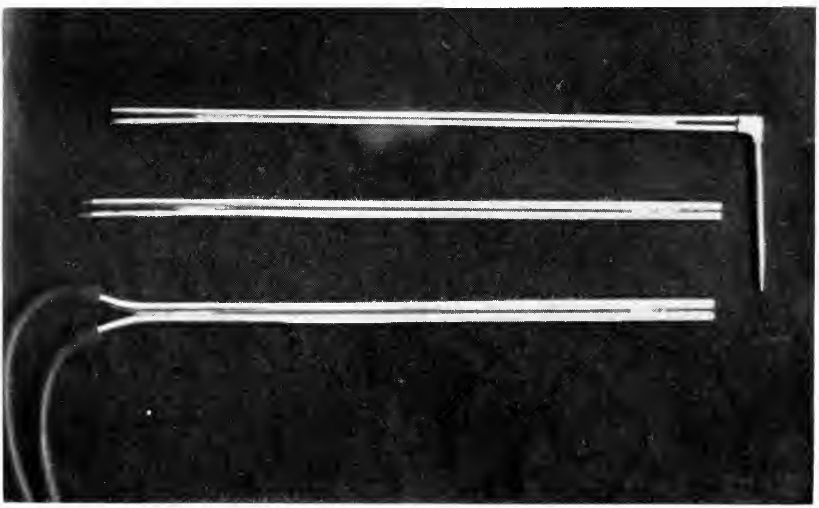


Plate No. 5. Pitot Tubes. See page 72.

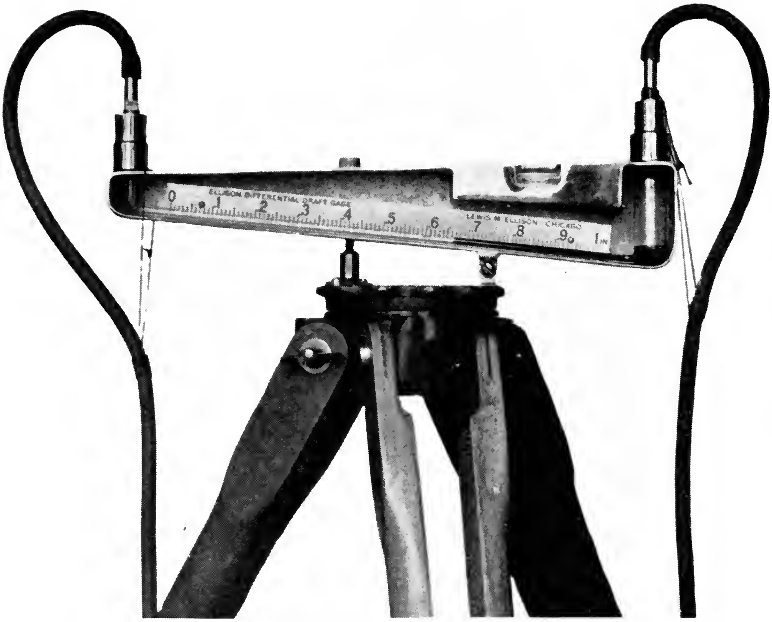


Plate No. 6. Ellison Draft Gauge. See page 72.

Plate No. 7. Ammonium Chloride Apparatus. See page 73.

Plate No. 8. Phenolphthalein Test Tubes.
See page 73.

Plate No. 9. Air Sampling Device. Paquelin Cautery. See page 74.

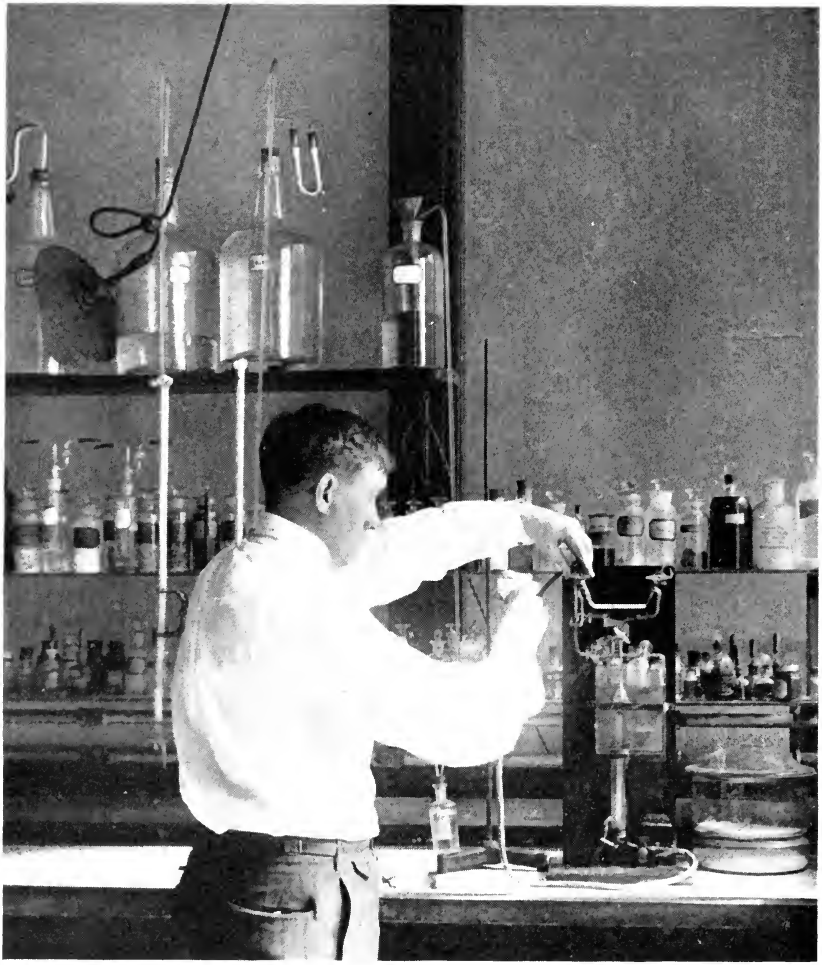


Plate No. 10. Analyses of Air Samples. Petterson-Palmquist Apparatus. See page 75.

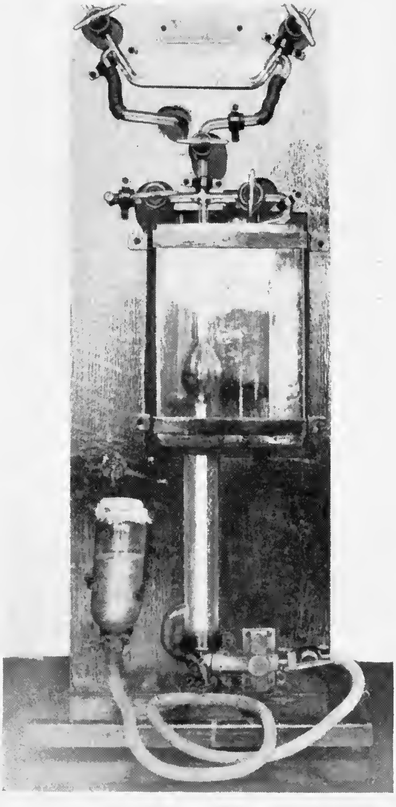


Plate No. 11. Petterson-Palmquist Apparatus. See page 75.

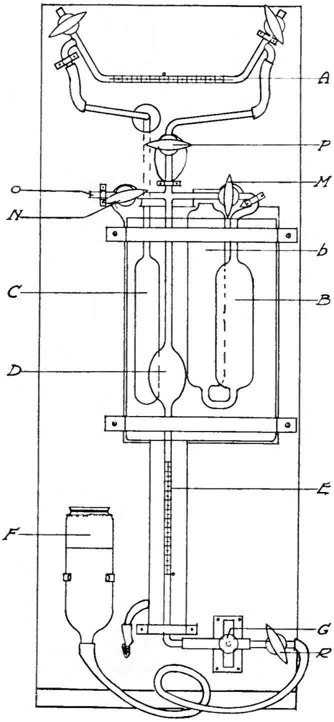


Plate No. 12. Petterson-Palmquist Apparatus. See page 75.

Plate No. 13. Culture Plate. See page 76.

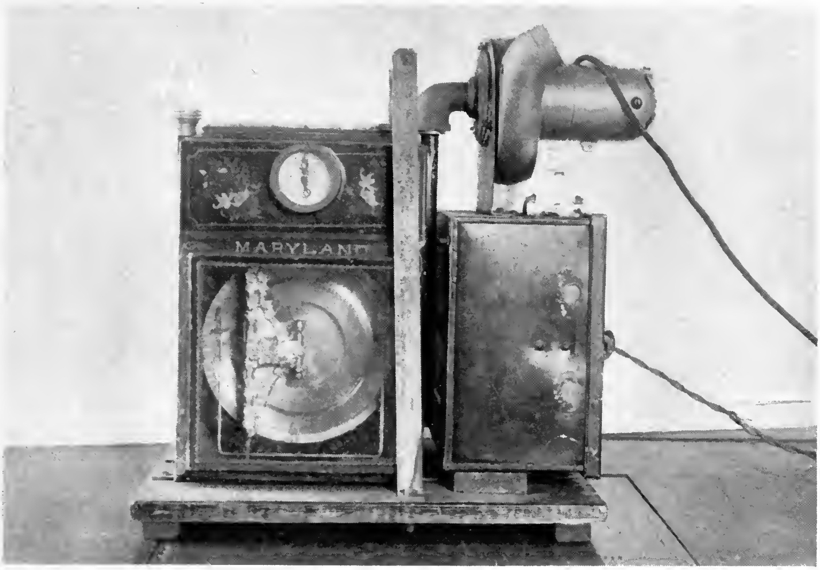


Plate No. 14. Sand Filter. See page 77.

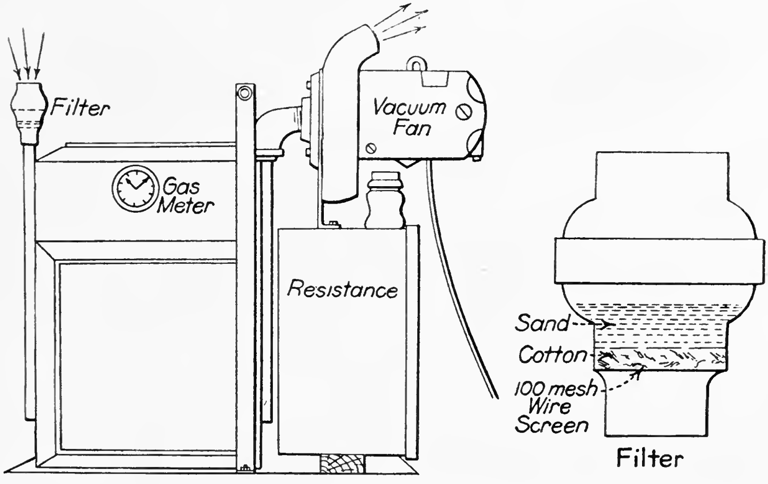


Plate No. 15. Sand Filter. See page 77.

Plate No. 16. Method of using Sphygmomanometer. See page 77.

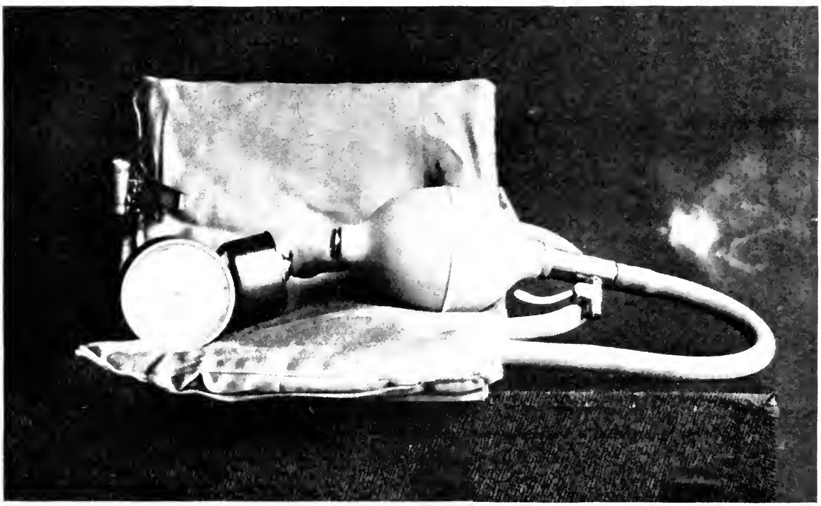


Plate No. 17. Sphygmomanometer. See page 78.

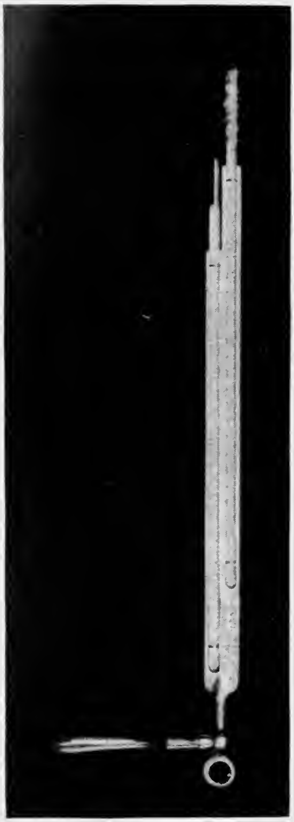


Plate No. 18. Psychrometer.
See page 78.

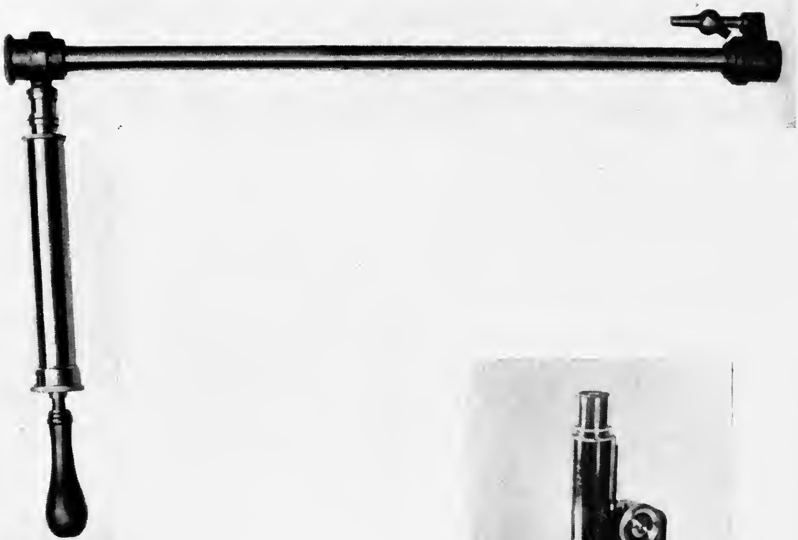


Plate No. 20. Koniscope.
See page 81.

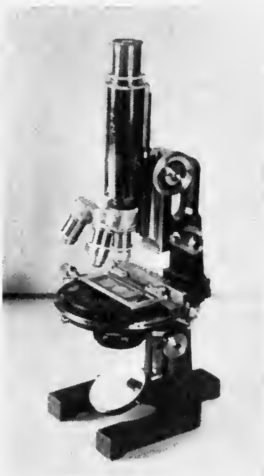


Plate No. 19. Sedgwick-Rafter Counting Cell on Microscope.
See page 79.

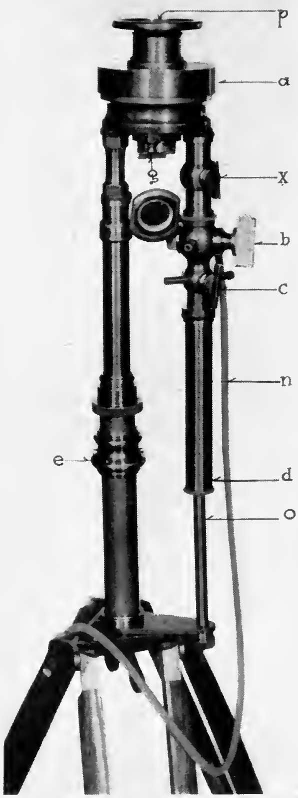


Plate No. 21. Aitken Portable Dust Counter. See page 82.